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High-temperature rotor bore dilatometer unit

By J. West, The Parsons and Marine Engineering Turbine Research and Development Association, Wallsend on Tyne, Northumberland

[*Paper received* 26 *June*, 1958]

The instrument measures optically the dilation due to centrifugal stresses of the bore of a steam turbine rotor under running conditions. The measurements are independent of vibration of the rotor. Light from an illuminated pinhole within an autocollimator is collimated on to a system of three mirrors supported kinematically inside a cylindrical cartridge, which is pushed into the rotor bore of the turbine. Two of the mirrors are fixed to the cartridge, and the third is hinged and connected to a feeler which is spring loaded against the rotor bore. With all three mirrors mutually at right angles, the light is reflected back to the autocollimator in exactly its own path, independent of any relative movement between the dilatometer and the autocollimator. On expansion of the rotor bore, the third mirror is displaced, tilting the returned beam of light. Since the turbine rotor is rotating, the image seen in the autocollimator appears as a circle, the diameter of which gives a measure of the dilation. The preparation of the mirror surfaces enabling them to withstand the conditions inside the turbine is discussed.

instrument described in this paper was developed for purpose of measuring centrifugal strain, under running ditions, in the rotor of the high-pressure cylinder of a)00 horse-power steam turbine in a position where the vailing temperature was 500° C and the maximum speed proximately 6000 rev/min.

)ne of the main difficulties to be considered in the design such an instrument was the fact that no reference point, tive to the turbine, could be fixed from which to measure iations in the diameter of the rotor bore while rotating, ing to the small, but sometimes violent, movements of the bine rotor position relative to its bedplate. Strain gauges e not been developed which are sufficiently stable for use high temperatures, and were therefore not used. Any chanical method of taking the measurements would have have some linkage analagous to a slip ring unit, and was ught impracticable.

he measuring system chosen was therefore an optical one, i was made self-compensating so that measurements taken the measuring unit were dependent only on changes of meter of the rotor bore, and not on movement of the rotor a whole, relative to the measuring instrument.

OPERATION

he measuring unit made use of the "corner cube" system three mirrors arranged at right angles to each other, which the property of returning a beam of light after reflexion all three mirrors, exactly in the path from whence it came, atever the angle of incidence or lateral displacement. e system is shown in Fig. 1. The mirror surfaces were ported on three metal segments, two of which were fixed h the third mobile. With all three mirrors originally usted to be mutually perpendicular, light falling on the tem would be returned in its own path. On dilation of rotor bore, the third mirror, the angular position of which dependent on the movement of a spring-loaded feeler, is ed about an axis perpendicular to that of the turbine, and returned beam tilted with it. Since the turbine rotor was ating, the returned beam described a cone, the apex angle which gave a measure of the amount of dilation of the or bore.

Two of the three segments were rigidly mounted kine- tically inside a cylindrical cartridge, supported by erically-ended, hardened steel adjusting screws (Firth's F.H.M. cutlery steel, by Firth Vickers Stainless Steels Ltd.), seated in a groove and hole at the mirror end of the cartridge, and the third screw resting against the smooth inner surface at the other end of the cartridge. The third, mobile, mirror segment was mounted similarly by two spherically-ended screws seated in a groove and hole at the mirror end of the cartridge, the third support being a feeler, which in use contacted the inside of the rotor bore through a hole in the cartridge.

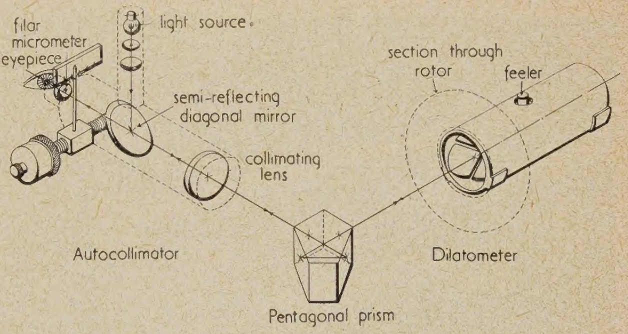

Fig. 1. General optical layout

To ensure that no deformation of the seats could take place during use, the holes and grooves were machined in small, hard F.H.M. steel inserts which were force-fitted into holes in the metal cartridge. These inserts had a tapered rim on the inner end which prevented their being pushed through the wall of the cartridge under the thrust of the adjusting screws.

The method and mechanism of adjustment of the screws used in alineing the segments in the cartridge was as follows. One of the two screws near the mirror end of each of the segments (the ones engaging the holes) were preset to an arbitrary position, and the three segments assembled in the cartridge, with a spring between them, as shown in Fig. 2 views (*a*) and (*d*), to hold the screws firmly against their seats while the instrument was stationary.

Final adjustments were made to any of the other screws after assembly through diametral holes in the other two segments and the cartridge, until the two "fixed" mirrors were found by inspection to be at right angles to each other. These adjusting screws were then locked in this position by tightening down a plate on the outside of each of the segments. This is illustrated in Fig. 2 (*b*) and (*c*), view (*b*) being a detail of this component on a larger scale.

The plates (1) each have a tapered hole with a split tapered bush (2) fitted inside it. The adjusting screws (3) pass through these bushes, and on tightening down the plate by a screw (4) at each end, are clamped in their adjusted position without displacement. These clamping screws are accessible from outside the instrument through holes in the cartridge. The components of the dilatometer unit are shown in Fig. 3.

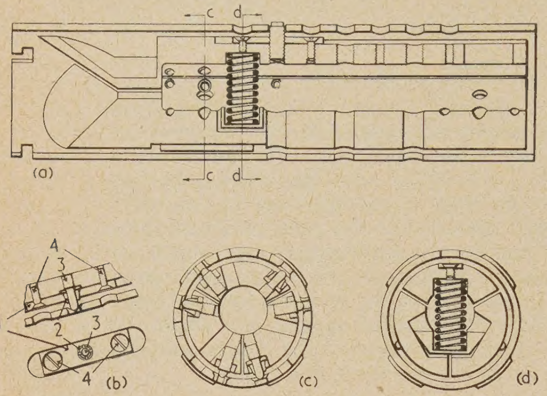

Fig. 2. Mechanical arrangement of dilatometer

(*a*), axial section on centre line; (*b*), detail of adjusting screws and locking devices; (*c*), section at *c–c*; (*d*), section at *d–d*.

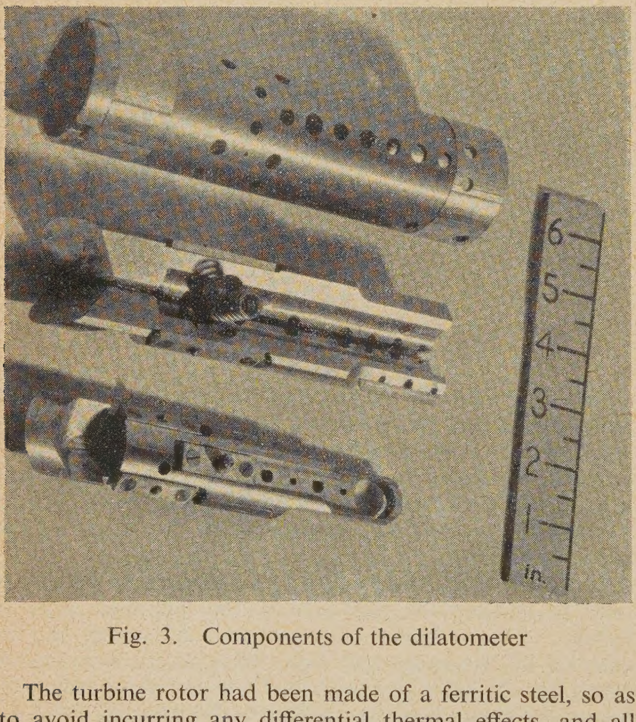

Fig. 3. Components of the dilatometer

The turbine rotor had been made of a ferritic steel, so as to avoid incurring any differential thermal effects, and all parts of the mirror supports and cartridge had to be made of steels with approximately the same coefficients of thermal expansion as that of the rotor. A slight discrepancy between these two values was corrected by making the feeler of a material of a higher coefficient of thermal expansion, so that the overall equivalent coefficient of thermal expansion of the dilatometer was equal to that of the rotor.

The instrument is deliberately unbalanced with respect the axis of the cartridge, so that when rotating, four pressu pads on the outside of the cartridge are forced into conta with that side of the rotor bore which lies opposite the poi of contact of the feeler.

The cartridge, which was an easy fit inside the rotor bor with its three mirrors adjusted to be originally at right angle was placed inside the rotor, at a point beneath the Curt wheel of the turbine, this being the point of maximu loading and hence maximum expected dilation of the roto

LIGHT SOURCE

The light source consisted of a modified 18 in. aut collimator (by Hilger–Watts Ltd.) fitted with a filar micr meter eyepiece. This produced a collimated beam of lig from an illuminated pinhole within the autocollimator, ar directed approximately along the axis of the dilatomete For practical considerations, a pentagonal prism was inte posed and the autocollimator pointed in a direction at rig angles to the axis of the turbine. The returned image of th pinhole was viewed in the eyepiece of the autocollimato and the diameter of the circle described on dilation of th rotor was measured with the filar micrometer.

CALIBRATION

The system was calibrated in the laboratory by movin the feeler in a series of steps, which were measured by sensitive clock gauge, and measuring the corresponding di placements of the images at the eyepiece of the autocollimato

The sensitivity of the system actually used for the measur ment of dilation was three minutes of arc (angular movemen of the return beam) for a dilation of the rotor bore of on milli-inch. A sensitivity of twice this may be achieved fo smaller dilations by reducing the distance between the feel and the pivots about which the mobile mirror tilts.

The diameter of the circle of light viewed in the eyepiec could be measured to an amount corresponding to an angula displacement of two or three seconds of arc with the magn fication of eyepiece used, which corresponds to a dilation o the rotor bore of approximately fifteen micro-inches.

MIRRORS

The development of a suitable reflecting surface for th mirrors, capable of withstanding the temperatures o approximately 500° C inside the rotor, and also conformin to the restriction concerning their coefficient of expansion required a great deal of experimental work. Firth's F.H.M cutlery steel was used for the most part, since this als allowed a reasonable polish to be applied to the ends of th segments, which were to act as the mirror surfaces.

To withstand the temperature inside the rotor, non corrosive surfaces on the mirrors were required to preven oxidation. All thin electrolytic deposits are porous to som extent, unless applied in such quantity that the optica quality of the base mirror would be lost. Most of them ar too soft to allow polishing accurately and cleanly.

A thick layer of hard chromium, deposited electrolyticall on to a backing of F.H.M. steel and subsequently polishe was also found to be unsatisfactory, mainly on account o stress cracks.

Another method investigated was to polish a piece of F.H.M steel rod from which the segments for the dilatometer ha been made, and to coat with aluminium by vacuum evapora tion. It was found that these mirrors were destroyed o eating because of gas evolution from the F.H.M. steel, and o preliminary outgassing treatment seemed to help.

It was attempted to seal off the gas in the F.H.M. steel egments by covering it with sheets of metal, the assumption eing that since the grain in the sheet was approximately arallel to the surface, less gas would diffuse up to the surface han from the segments in which the grain penetrated the urface. The following metals were tried: rhodium, Inconel,* Nimonic,* carbon steel and F.H.M. steel. Only the latter was successful. (Thickness: 0·125 in., furnace brazed, with opper in hydrogen.)

The surface of the sheet was polished and coated with uccessive layers of quartz, aluminium and quartz. (The uartz underlay prevented interdiffusion of F.H.M. steel and luminium during heating.) After considerable experimental djustment of the thicknesses of the aluminium and quartz, satisfactory surface was finally obtained which stood up o several days use at 500° C.

The dilatometer remained inside the hot rotor of the turbine for upward of three hundred hours, during the various trials on the turbine, without disabling deterioration of the mirror surfaces.

The programme of trials required on this turbine was a very full one, and it was not possible, in the time allotted to rotor bore measurement, to achieve exact temperature compensation between the dilatometer and the rotor, since this must for the most part be experimental in nature. Readings taken under similar conditions, however, showed good agreement, and the instrument was found to be quite stable at the very exacting running conditions under which it was used.

ACKNOWLEDGEMENTS

I am indebted to the Director of Pametrada, and the Admiralty, who sponsored this work, for permission to publish this paper, and to Sir Howard Grubb Parsons Ltd. for their co-operation in the development and production of the mirrors. The original design of the instrument was conceived by Dr. O. P. T. Kantorowicz.

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* Manufactured by Henry Wiggins Co., Birmingham.

Impaction sampler for size grading air-borne bacteria-carrying particles

By O. M. Lidwell, D.Phil., Central Public Health Laboratory, Colindale Avenue, London, N.W.9

[*Paper first received* 28 *July, and in final form* 15 *September*, 1958]

A sampler for air-borne bacteria is described which separates the sample into four fractions each collected on to the agar surface of a Petri dish. The sampling rate is approximately 20 ft^3/min, the size limits to the fractions are, above 18 μ diameter, between 10 and 18 μ, between 10 and 4 μ and below 4 μ. There is considerable overlap between the fractions but reasonable estimates of the median particle diameter and the dispersion of particle size within the sample can be made so long as these fall within the working limits of the instrument.

A complete description of the air-borne bacterial flora of a given environment at a given time, in terms of viability, species, particle size and the distribution of aggregates of organisms, is only practicable in exceptional, and generally artificially simplified, situations. It is therefore usually necessary to confine the analysis to some specified properties. Most published observations have been limited to the numbers of bacteria-carrying particles, the cultural method being varied according to the species of interest. Where liquid media have been used for collection or culture, bacterial aggregates may have been broken up and the final count more nearly represent the total numbers of bacteria, as opposed to numbers of bacteria-carrying particles. Only relatively crude attempts have been made to examine the bacterial aggregates in a natural air-borne flora.$^{(1)}$ Some estimates have been made of the size of the suspended material by comparison between the numbers collected from a given volume of air and those sedimenting on to a given horizontal area in a fixed time.$^{(2, 3)}$ This method is, however, not generally very accurate and provides only limited information.

The cascade impactor,$^{(4)}$ which separates an air-borne dust into a series of graded size fractions by successive impaction at increasing velocities, has been used for the examination of artificially formed bacterial aerosols,$^{(5)}$ but is not convenient for the study of naturally occurring populations of air-borne micro-organisms. The instrument described in this paper employs the principles of the cascade impactor in such a way that size graded samples can be obtained directly on the surface of solid culture media. A sampling rate of approximately 20 ft^3/min and the use of $5\frac{1}{2}$ in. diameter Petri dishes enable samples derived from 300 ft^3 of air or more to be obtained in a reasonably short time.

CONSTRUCTIONAL DETAILS

Sectional drawings of the instrument and a photograph are given in Figs. 1 and 2 while certain specific dimensions can be found in Table 1. Jet 1, the first impaction stage, is in the form of an annular gap in a hinged metal cap over the uppermost Petri dish. The Petri dish, like the two immediately below it, has a central hole to carry the air stream to the following stage with a minimum loss of suspended particles. These dishes are prepared by drilling a 2 in. diameter hole in the centre of the bottom of a standard $5\frac{1}{2}$ in. glass Petri dish, using a tubular cutter fed with a carborundum water slurry. A stainless steel ring fits easily into this hole and the plates are prepared for use by pouring molten agar into them until its level rises above the lip of the ring, giving a smooth air flow contour. This operation can be performed without difficulty.

Jet 2 consists of an outer copper shell with an internal concentric deflector moulded from resin/glass fibre. The gap between these is so proportioned as to give a steady increase in air velocity up to the final short parallel section. The whole assembly is mounted in a collar which can be raised or lowered by rack and pinion or other means so as to control the separation between the lower slit edge and the agar surface. The correct separation is indicated visually by observing the reflexion in the agar surface of a spike mounted on the lower slit edge. The length of this spike is made equal to two-thirds of the desired separation, so that when the spacing is correct the visual gap between the top of the spike and its image is equal to the length of the spike itself.

Jet 3 is similar to jet 2, the only difference being the modifications necessary in the deflector dimensions to produce the desired jet size.

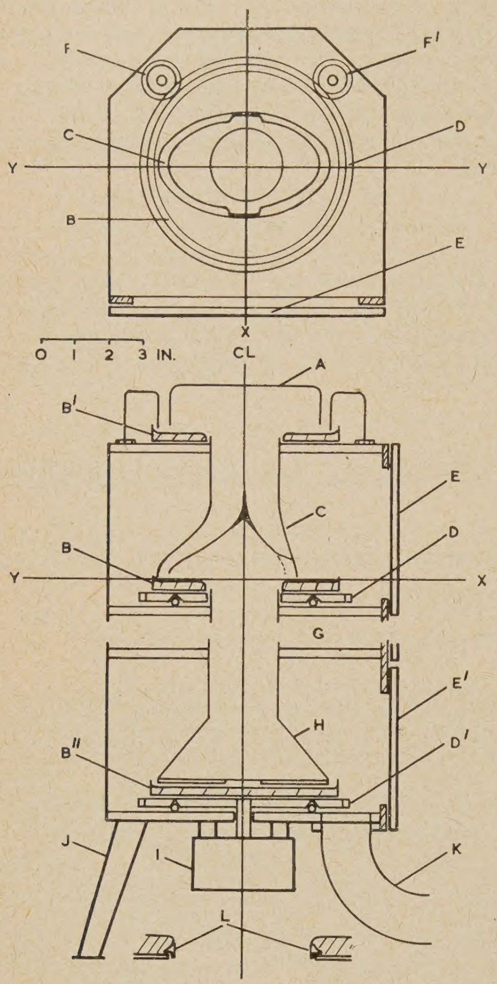

Fig. 1. Simplified sectional drawings of the instrument

The upper figure is a horizontal section through the plane of jet 2. Some features lying just above or just below the plane are included. The lower figure is composed of two vertical half sections. The left-hand portion is a transverse section, the right-hand portion a fore and aft section both through and meeting on the central axis of the instrument

A, cap with jet1; $BB'B''$, $5\frac{1}{2}$ in. Petri dishes with agar medium; *C*, jet 2 with concentric deflector; DD', rotating turntables carried on ball bearings; EE', Perspex doors; FF', drive gears; *G*, jet 3 is similar to jet 2 and this stage is omitted from the drawing; *H*, jet 4; *I*, drive motor, Venner synchronous type MT; *J*, leg—the three legs are placed at 120°, one being centrally disposed at the back; *K*, outlet to suction pump. Actually placed to the side at the rear of the instrument; *L*, detail of stainless steel ring in bored Petri dish with agar medium. Shown to larger scale ($\times 2$ compared with other components).

In order to attain efficient impaction down to the smallest particle sizes without excessive increase in the air velocity and the suction pressure required for operation, it was necessary to provide for a much larger slit length in the fourth stage. This has been attained by employing eight radial slits on the base of a conical shell. No deflector has been used since the particles that have passed jet 3 are sma enough not to impact seriously in the turbulent air conditio within the cone. The correct separation between the sli and the agar surface is more critical at this stage. Two silv wires, one insulated, are attached to the base of the she These project downwards 1·9 mm beyond the slit and a connected to the mains supply through a small neon lam and two $\frac{1}{4}$ MΩ resistances. After inserting a plate the sli are lowered until the points of the two wires make conta with the agar and the neon lamp glows. The slits are the retracted until the glow is extinguished. This leaves a sma gap between the bottom of the wires and the agar surface which avoids scoring by the wires as the plate rotates during sampling. The working distance between the lower edge of the slits and the agar surfaces is then approximately 2 mm.

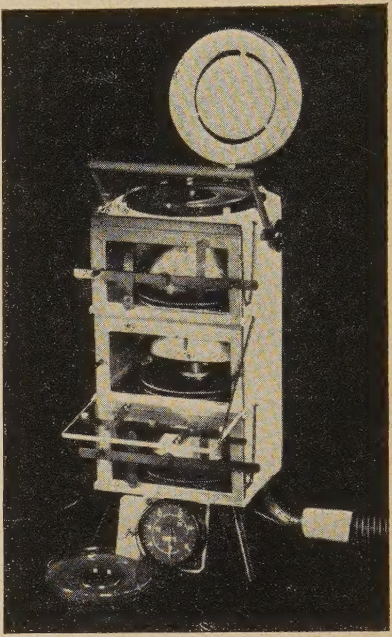

Fig. 2. The size-grading sampler

Jet 1 is hinged back and the annular jet is visible, as is also the plate which has been placed in position in stage 1. A plate has been inserted into stage 2, the jet lowered into position and the door closed. Stage 3 is open ready to be loaded, the plate itself is lying in front of the sampler and shows the central metal ring. Stage 4 is closed but not yet loaded. The air pressure in the last stage is given by the aneroid manometer, taken from an air speed indicator. A reading of 13·5 (135 knots) corresponds to 12 in. negative water pressure.

The lower three Petri dishes are all rotated by a common drive in order to distribute the deposited material more uniformly over the agar surfaces. The fourth and last Petri dish is a standard $5\frac{1}{2}$ in. dish since the air after this impaction is to be discarded and subsequent losses, if any, are immaterial. Access to these three dishes for loading and unloading the sampler is through three Perspex doors which are clamped down by spring pressure on to $\frac{1}{4}$ in. Rubazote sealing flanges (by Expanded Rubber Co. Ltd.). The rate of air flow is controlled by an aneroid manometer which indicates the suction pressure within the last chamber. At 12 in. water gauge the rate of sampling is approximately 22 ft^3/min. The apparatus is designed for sampling from still or near still air, i.e. within the range of air movement found in normal occupied rooms. In these circumstances the errors of sampling due to the impracticability of establishing isokinetic sampling nditions are insignificant. The faired entry to jet 1 is signed to equalize the distribution of the collected sample er the cross-section of the jet.(4)

PERFORMANCE

ethods

The performance of the instrument can be predicted from e data given by May(4) for the cascade impactor, or ternatively calculated according to the formulae derived by avies(6) (see Table 1 and Fig. 2). These two differ chiefly that the calculated cut-off on any jet is much sharper than at found experimentally by May. An alternative form of scade impactor has been described(7) which, it is claimed, ves a sharper cut-off than May's original design. The inciple of construction is not, however, conveniently lapted to the purpose of the instrument described in this iper.

Table 1. *Jet dimensions, and particle diameters for 50% penetration (d_{50})*

Jet No.	*Form*	*Width (cm)*	*Separation from agar surface (cm)**	*d_{50} observed (μ)*		*d_{50} calculated according to:*	
				direct	*corr.*	*Davies*	*May*
1*A*	Circular annulus 12·5 cm outside diameter	1·10	1·10	24	28	21	16
1		0·70	0·70	15·7	18·2	14	12
2	Elliptical annulus 12·5 × 7·5 cm outside diameter†	0·50	0·50	8·4	9·6	9	8
3		0·25	0·25	3·7	4·2	4·4	4
4*A*	Diametral, 12·5 cm‡	0·18	0·18	2·0	2·3	1·8	1·6
4	Eight radial totalling 35·6 cm§	0·05	0·20	<1·0	(0·9)	1·1	0·8

The values of d_{50} observed, direct, are those obtained by interpolation using the median diameter of the dye particles as measured ı the microscope. The corrected values have been adjusted to unit density and for the dispersion of particle size in the dye clouds nployed. The jets with suffix *A* were early forms used in some of the tests but later discarded.

* The outer wall of jets 1*A* and 1 was carried down to 3 mm, and that of jets 2 and 3 to 2 mm from the agar surface.

† At each end of the minor axis 2 cm of the annulus, i.e. that part nearest to the centre of the Petri dish was blocked.

‡ The central 2·5 cm of the diametral slot was blocked giving a jet length of 5 + 5 cm.

§ Four jets 5·1 cm long at 90° with four jets 3·8 cm long bisecting the angles between the larger jets. The outer ends of all eight jets y on the circumference of a circle 12·7 cm in diameter.

Experimental determinations of the performance of each t and of the losses within the instrument were made in a ariety of ways: (*a*) by samples taken from a homogeneous oud of dye particles; (*b*) by samples taken from a cloud of *acillus subtilis* spores dried on to talc powder; and (*c*) by omparison of the counts obtained from samples taken in ccupied places with those obtained from simultaneous ımples taken by other instruments.

(*a*) A substantially homogeneous cloud of dye particles 'as generated by feeding an aqueous sodium fluorescein olution on to a high-speed spinning disk.(8) This cloud 'as drawn down into a cabinet approximately 2 × 2 × 3 ft rom which samples were taken. The particle size was ontrolled by varying the solution concentration and estiıated by microscopical measurement of samples collected ı a cascade impactor; only one jet, appropriate to the article size involved, being used. The air of the cabinet 'as mixed by a gently oscillating fan and the bulk conentration of dye particles in the air estimated by isokinetic ampling through filter paper disks (Whatman No. 41) at he ends of a rotating arm. The Petri dishes for these experinents were filled with a 1·5% water agar. This agar had een purified by solution in hot water, solidifying, breaking lown the gel by freezing, expressing the free water and hen repeating the process. Extraction of the fluorescein rom the plates after sampling was facilitated by freezing to reak the gel before making up into a fixed volume with listilled water. All fluorescein solutions were estimated olorimetrically, either by absorption or, for the weaker solutions, by fluorimetry, using long-wave ultra-violet light to excite the fluorescence.

Estimates of losses were obtained by washing out all the jets separately with distilled water after each experiment, and, in the experiments with particles of 4 μ or less, assessing the proportion of the cloud not collected in the instrument by passing the effluent air through a cotton wool pad which was then eluted with water and the fluorescein extracted estimated as above. The collection efficiency of this pad was adequate at least down to 1 μ, since the total recovery of dye at this particle diameter was still close to 100% of that indicated by the parallel filter paper samples. Nearly 20% of the total was then recovered from the pad.

(*b*) A cloud of *Bacillus subtilis* spores dried on talc powder was dispersed into the air of a 2000 ft^3 room. Parallel samples were taken at intervals with the "large" slit-sampler,(9) a single stage impaction sampler with a high collection efficiency for bacteria-carrying particles, and with the size-grading sampler. The air of the room was continually mixed throughout each experiment with a small table fan.

(*c*) Over a series of samples taken in clerical offices the total collection on the size-grading sampler was compared with the numbers collected in simultaneous samples by a slit-sampler. In most of these observations an early version of jet 4 was employed, which was inefficient at equivalent particle sizes below 2 μ. It is not thought that this significantly affects the comparisons in view of the apparent size distribution of the collected material.

Results

(*a*) *Experiments with dye particles.* When the values for percentage penetration through the individual jets were plotted against the mean particle diamaters the shape of the curve appeared to be similar for all the jets tested, although there was a good deal of scatter in the individual determinations. Estimates of the particle diameters corresponding to 50% penetration (d_{50}) were derived from these curves for each jet. The individual experimental points, some fifty in all, were then plotted on one chart with the logarithm of the ratio of the actual measured mean particle size (d) to the estimated particle size for 50% penetration (d_{50}), i.e. $\log(d/d_{50})$ as abscissa and the observed percentage penetration as ordinate. Curve (1) in Fig. 3 is that drawn by eye through these points. There is some divergence from the curve given by May for the geometrically similar cascade-impactor jets. This divergence can be accounted for, at least in part, as a result of the dispersion of particle size in the cloud. The effect of the small variation in particle diameter is increased by the use of a quantitative assessment of the collected dye, which is dependent on particle mass, rather than on a count of particle numbers.

Losses of approximately 9, 9 and 4% of the material passing into jets 2, 3 and 4 respectively were indicated by the amounts of dye recovered on washing out the jets after each experiment. The magnitude of these losses did not appear to be dependent on particle diameter.

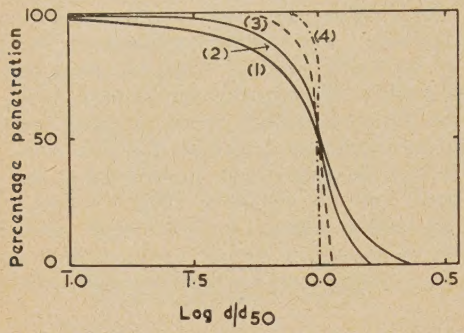

Fig. 3. Penetration curves for jet impactors

d, particle diameter. d_{50}, particle diameter for 50% penetration. Curve (1), results obtained with dye particle clouds; curve (2), curve given by May(4) for the cascade impactor jets; curves (3) and (4), curves calculated according to the formulae given by Davies(6) for two different values, 2·0 and 1·0, of his parameter α. This parameter, which is a function of the width of the jet and its separation from the surface on to which impaction is taking place, takes a value of 1·9 for jets 1, 2 and 3 and a value near to 1·0 for jet 4. For the jets of the cascade impactor it takes a value near to 2·0.

(*b*) *Experiments with spore-bearing talc powder.* The results of these experiments are shown in Fig. 4. When allowance was made for the respective volumes sampled, the sum of the numbers of colonies counted after incubation on the four stages of the size-grading sampler was approximately 80% of that found on the corresponding plates of the "large" slit sampler. This fraction showed no significant change throughout the course of the experiment. The apparent loss of 20% is rather greater than the approximately 11% estimated from the dye experiments for losses in the jets for clouds having the size distributions of the spore-bearing talc. The difference may be wholly or pa experimental error but it seems likely that there may be sm losses in other parts of the apparatus not examined in dye experiments.

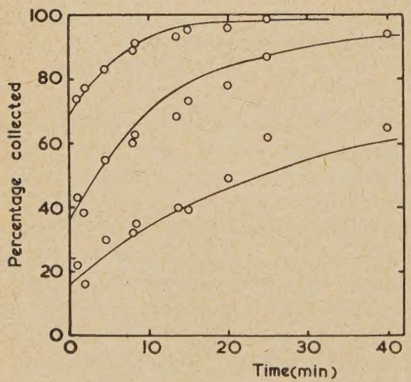

Fig. 4. Changes in the size distribution of a cloud of *Bacillus subtilis* spores on talc powder during sedimentation in a small room

The three lines and their associated points define the proportions impacted by the four jets, e.g. after 20 min 49% was found on stage 4, 78–49 = 29% on stage 3, 96·5–78 = 18·5% on stage 2 and 100–96·5 = 3·5% on stage 1.

The full lines drawn through the points in Fig. 4 h been obtained as follows: (1) the particle-size distribution the initial cloud was determined in the way described bel (2) the size distributions derived from this initial distribut by the action of sedimentation for various times were t computed. The general assumptions and the method calculation were similar to those described previously((3) the relative numbers of particles which would be collec on the four sampler stages from clouds of these compu size distributions were calculated by using the distribut curves of Fig. 5 (see below). The general agreement betw these computed lines and the observed course of the expe ments confirms the distribution curves given in Fig. 5 a the method of assessing the particle size distributions deri from them.

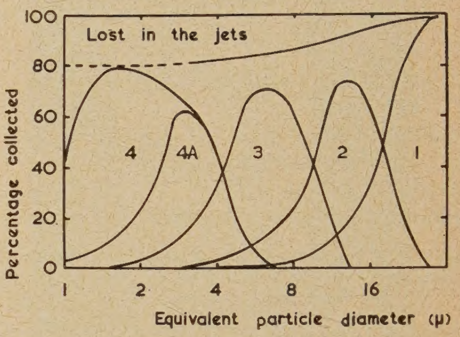

Fig. 5. The relative proportions of particles of variou sizes deposited in the four stages of the sampler

Each of the five lower curves defines the proportions collected in the stage following the jet corresponding to the numb written below the curve. The upper curve defines, by difference, the sum total of the losses in the 2nd, 3rd and 4th jets; d_{50} for jet 4 has been taken as 1·0 μ.

(*c*) *Field samples.* The observations are summarized Table 2. The overall mean for the percentage collect grown and counted is 80% of that found on parallel sampl taken with a slit sampler. This is identical with the figu

Table 2. *Percentage of air-borne organisms collected a counted*

	Serum agar medium	*Selective medium*		
Site	*General count*	*Total grown*	*Streptococci*	*Str. salivarius*
A	70 (2)	80 (9)	94 (7)	80 (9)
B	56 (5)	87 (14)	104 (11)	98 (14)
C	66 (7)	73 (13)	71 (10)	76 (14)

The number of samples on which a given percentage is based given in brackets after each figure.

deduced from the experiments with spore-bearing talc powde In addition to random variation some systematic difference appear as between the different bacterial species enumerate and the medium employed. This is probably related primaril to the density of growth on the plates. For the serum aga series the comparative samples were taken on a machin sampling at 1 ft^3/min on to 4 in. dishes. The colony densit was two to five times heavier on the samples taken in th size grading sampler. The series on selective media wer done using a slit sampler employing 5½ in. dishes and sampling rate of 25 ft^3/min. The apparently slightly highe ollection of the defined species may here reflect more ficient searching or characterization on the rather less rowded plates of the size-grading sampler.

DISCUSSION

Only a limited amount of information about the size istribution of a cloud of air-borne bacteria-carrying particles an be obtained by enumeration of the numbers found in no ore than four fractions. The precision of the information btained from the instrument described is also reduced by ne appreciable overlap between the fractions. It is, thereore, important to consider the extent of the conclusions hich can be validly drawn. The most important paraneters of the machine which influence this are the cut-off urves for the individual jets, both their shape and the particle zes giving 50% penetration, and the losses in the successive ts.

It has seemed best to assume a penetration curve similar that of the cascade impactor, in spite of the apparent ivergence from this shown by the dye particle results Fig. 3). As has been said earlier, part at least of this diverence must be due to inhomogeneity in the dye particle loud. In addition the experimental results obtained with a ariety of bacterial clouds, in particular those with spore-earing talc referred to above, lead to fractionations of the loud between the four stages which are compatible with the ascade impactor penetration curve, but cannot be reconciled ith the curve for dye particles as given in Fig. 3.

The particle sizes at 50% penetration, as estimated by irect microscopic examination of the dye particles, need orrection to give the true value of the "equivalent particle iameter," this being the diameter of a spherical particle of nit density which sediments or impacts similarly to the article in question. The variation in size of the particles in given dye cloud and the density of the sodium fluorescein articles (1·3–1·4 g/cm^3) need to be taken into account. The ombined effect of these two factors, using an estimate of homogeneity derived from the microscopic measurements f particle diameter, is to multiply the measured particle ize at 50% penetration by approximately 1·15 to give the quivalent particle diameter.

The losses in the instrument as a whole appear to be somehat greater than the sum of the losses in the jets as deterined from the experiments with dye particles. As there is o evidence as to the site of such losses they cannot be taken nto account in the computation of size distribution, although hey may, and probably should be, in estimating the total umber of particles in the sample.

The relative proportions of particles of various sizes eposited in the four stages (and lost in the jets) have been omputed from the cascade impactor penetration curve, sing the corrected values for equivalent particle diameters t 50% penetration from Table 1 and the values for losses iven by the experiments with dye particles. The results of his computation are exhibited in Fig. 5. With an overlap f the size indicated in this figure, the approximately 2 : 1 atio between the particle sizes for 50% penetration on uccessive jets represents as close a fractionation as is profitble with the instrument. The 50% penetration diameter or jet 1 cannot be raised above 20 μ without excessive eposition on the deflector of jet 2.

If hypothetical log-normal distributions of particles are istributed on to the four stages of the sampler by means of ne data of Fig. 5, and the cumulative percentages on the uccessive stages plotted as cumulative percentages oversize on log-probability paper, at values equal to the values for 50% penetration, then the three plotted points usually lie close to straight lines approximating to those for the generating distributions. The median diameters estimated by interpolation on these lines appear to be correct within 10–15% so long as the fraction deposited on stage 1 lies between 1·0 and 90% and if correction for losses in the jet is made by multiplying the stage deposits by the following factors before evaluating the figures for cumulative percentage oversize. Stage 1, 1·00; stage 2, 1·10; stage 3, 1·20; stage 4, 1·25. These factors are derived directly from the estimates of the losses in the jets obtained in the experiments with dye particles. The estimates of standard deviation derived from the same lines are less good but appear to be within 20% if the following conditions hold in addition to that for reliable estimation of the median diameter; the indicated median particle diameter exceeds 8 μ and the indicated standard deviation is not less than 0·20 (logarithmic units to the base 10); or the indicated median particle diameter lies between 4 and 8 μ and the indicated standard deviation is not less than 0·30; or the indicated median particle diameter lies between 2 and 4 μ and the indicated standard deviation is not less than 0·40.

From all the above considerations it would appear that, within the limitations indicated, a reasonable assessment of the numbers of air-borne bacteria-carrying particles and their size distribution can be obtained with this instrument by the following method. The numbers collected on stages 1, 2, 3 and 4 are multiplied by the factors 1·00, 1·10, 1·20 and 1·25 respectively, and the figures thus obtained are related to an air sampling rate of 20·0 ft^3/min. The cumulative percentages oversize are then plotted on probability paper at 18·2, 9·6 and 4·2 μ respectively, i.e. at the corrected values for 50% penetration of jets 1, 2 and 3. The scale of particle size may be either logarithmic or arithmetic according to convenience. Among a large number of samples which have been taken in a variety of situations, the majority appear to conform more closely to a normal distribution in the arithmetic value of the particle diameter within the range 4–18 μ, but many lie between this and the log-normal form while some appear to conform quite closely to the log-normal form itself.

In assessing the results for any given set of measurements it is, of course, necessary to allow for the statistical and other errors in the estimate of the cumulative fractions as well as the possible errors in interpreting these fractions in terms of median diameter and dispersion. It may also be pointed out that bacteria, in general, are not smaller than about 1·0 μ in diameter so that all the indicated distributions must in fact be truncated at or near this value. Some distributions which have been encountered, the spore-bearing talc powder used in the experiments recorded here being a particularly clear example, appear to be bimodal with a second frequency maximum near to the truncation point; this may well correspond to a proportion of micro-organisms in the cloud almost or entirely free from other adherent material.

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Electrolytic potentiometer as a general purpose physiological transducer

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The use of the electrolytic potentiometer as a transducer for physiological measurements is described. Two suitable types of amplifier circuit are given; one in which the output from the electrolytic cell drives a cathode follower as a stable power amplifier, and another in which a second electrolytic cell is coupled to a recording milliammeter, and the latter used as a phase sensitive servo-motor to balance changes in the measuring cell. A transistor amplifier circuit suitable for portable equipment is given as part of the second application.

The principle of the electrolytic potentiometer as a basis for physiological recording systems does not appear to have been fully exploited. Electrolytic resistances have been known for a very long time and have been used for the handling of high powers in industrial equipment for fifty years.⁽¹⁾ The electrolytic potentiometer or voltage divider follows logically from the principle of the electrolytic resistor, but the only application which has appeared in a cursory examination of the literature is a mechanical-electrical transducer described by Manzotti.⁽²⁾ Manzotti used an exploring electrode in a uniform field as a means of detecting small movements. His system requires the use of a considerable gain in the amplifier following it. As the construction of amplifiers with a stable gain is not simple, it was thought worth developing the principle in a manner which would simplify the design of a stable amplifier or eliminate the need for stabilization altogether.

CONSTRUCTION OF POTENTIOMETER

Essentially, an electrolytic potentiometer is a vessel containing a suitable electrolyte within which a uniform field is produced by means of two electrodes. The exploring electrode moves along the field between the electrodes within a region where the field is quite uniform. The most satisfactory electrolyte for such purposes is distilled water, which gives a high impedance and thus makes it possible to use relatively high voltages, while stainless steel would seem to be the ideal material for the construction of electrodes. An electrolytic potentiometer intended for general-purpose recording in a physiological laboratory is shown in Fig. 1. It consists of a small cylinder of Perspex fitted at each end with a stainless steel plug to which an electrical connexion may be made. A slot runs the full length of the cylinder and the exploring electrode moves within this. The assembly is fitted to a holder which permits it to be moved along the axis of the cylinder, thus simplifying zero adjustment.

The advantages of using this system as a transducer are many. Any range of movement may be applied by the suitable construction of the cell. Because the explori electrode moves within an electrolyte, the system is infinitel graded and thus is superior to the low torque mechanica potentiometer which is frequently used for similar appl cations. The friction offered to the movement of the explorin electrode by distilled water is extremely light and, in an case, appears as a form of damping which for many appl cations is an advantage. Because of the high impedance o distilled water as an electrolyte, it is possible to use quite high voltages; in fact, in the case of the cell described i which the electrodes are 2·5 cm apart, an alternating voltage of 100 V may be safely applied, thus making it possible t drive a power pentode valve as a cathode follower and t obtain a large power amplification with stable gain because of the feedback action of the cathode follower. This makes the electrolytic potentiometer much more convenient to use than strain gauges or differential transformers for the measurement of small pressure changes or the movements of small pieces of tissue.

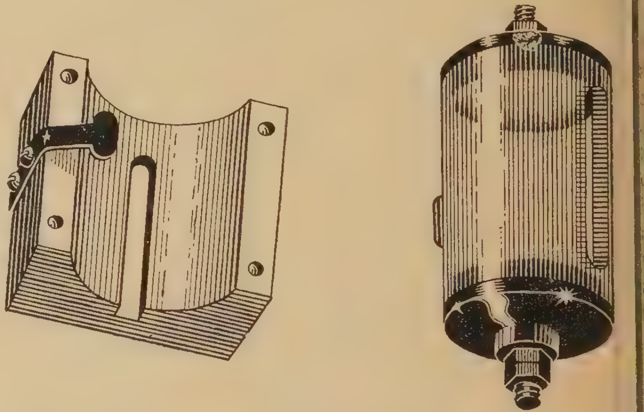

Fig. 1. Diagram of an electrolytic potentiometer suitable as a transducer for physiological measurements. Distance between electrodes, 2·5 cm; internal diameter approximately 1·5 cm

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APPLICATIONS OF PRINCIPLE

Two general systems for the application of the electrolytic otentiometer principle have been studied. The first system ses the electrolytic cell as a potentiometer supplied from a onstant alternating voltage source. The exploring electrode ius serves as a voltage divider and gives an output voltage roportional to displacement. Fig. 2 shows the circuit used or this application of the electrolytic cell. The circuit is ivided into two sections, a simple voltage regulator and the mplifier and recorder. A double triode valve V_1 is fed hrough a potentiometer from a 12·6 V heater winding on ie power transformer of the instrument. This voltage is mplified in the first stage of the double triode and the output rives the second stage as a cathode follower which functions s an impedance converter and power amplifier. The output rom the cathode follower is applied across a bridge, which onsists of a thermistor R_9 and resistor R_{10}. The voltage etween the two resistors is fed back to the input grid of the mplifier. If the output voltage of the cathode follower ends to rise, the resistance of the thermistor falls, increasing ie amount of negative feedback and thus tending to stabilize ie output. In order to maintain the thermistor at its most atisfactory working range the voltage divider, consisting of esistors R_{11} and R_{12}, is connected across the output, so naking it possible to set the voltage applied to the electrolytic otentiometer to suit the recording instrument. The output rom the potentiometer is fed to V_2, which is connected as a athode follower; the output of V_2 is supplied *via* a germanium iode bridge rectifier to an Elliott 0–2 mA recorder. A ariable resistor R_{16} is connected in series with the meter novement as a means of calibrating the instrument. If a ource of regulated alternating current is available there is o need for the regulator described in this circuit, all that is eeded being the electrolytic potentiometer supplied from a table voltage and the cathode follower amplifier. The athode follower is used as a method of getting enough ower to drive the recording meter. Because of its inherently igh input impedance it is an ideal method, in that virtually o load is placed on the exploring electrode and thus there s no distortion of the field. Because of the 100% feedback f the cathode follower, changes in tube characteristics or in upply voltage do not affect its gain over a very wide range.

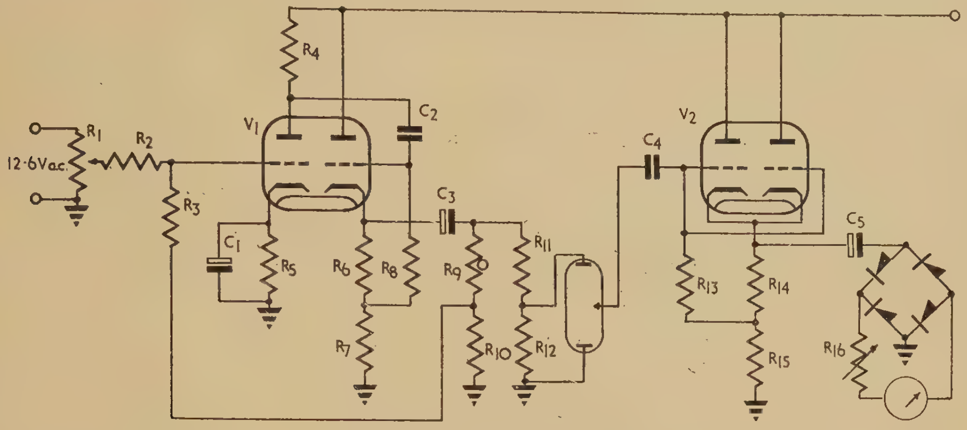

Fig. 2. Circuit showing application of electrolytic potentiometer for general physiological purposes

R_1 = 20 kΩ potentiometer
$R_{2,\,3}$ = 0·5 MΩ carbon
R_4 = 100 kΩ carbon
R_5 = 7 kΩ carbon
R_6 = 1 kΩ carbon
R_7 = 100 kΩ carbon
R_8 = 1 MΩ carbon
R_9 = S.T.C. "thermistor" A1522/100
R_{10} = 7 kΩ carbon
R_{11}, R_{12} = adjusted to suit the voltage required on the electrolytic potentiometer. May be omitted when used with 0–2 mA Elliott recorder
R_{13} = 1 MΩ carbon
R_{14} = 200 Ω carbon
R_{15} = 2·5 kΩ carbon
R_{16} = Variable wire wound depending on type of recorder used; 5 kΩ was used with Elliott 0·2 mA recorder
C_1 = 50 μF electrolytic
C_2 = 0·1 μF paper
C_3 = 8 μF electrolytic
C_4 = 0·1 μF paper
C_5 = 16 μF electrolytic
V_1 = 12AX7
V_2 = 12AU7

One "brute force" version of this system which was tested used a 6L6 power pentode as the amplifier, with the output transformer in the cathode circuit. This makes it possible to obtain about 5 W of power with stable gain, though of course the input voltage needed is substantial.

Fig. 3 shows a simple circuit which is quite adequate for many purposes in the physiology laboratory. The voltage supplying the electrolytic cell is stabilized by using a negative temperature coefficient resistor in series with a suitable carbon resistor. Both are fed from the 230 V a.c. mains *via* a high wattage wire-wound resistor. Using a Philips N.T.C. resistor of about 2 kΩ resistance at room temperature in series with 100 Ω and adjusting the current to about 80 mA, it was found possible to obtain a relatively stable voltage of 20 V. Slow changes in mains voltage are compensated for by the changing resistance of the N.T.C. resistor.

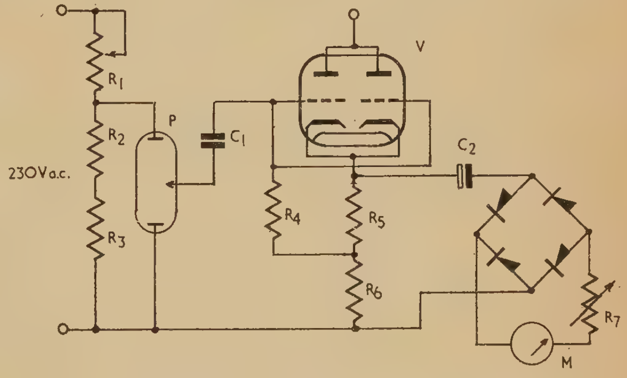

Fig. 3. Simplified circuit for use with electrolytic potentiometer where low degree of accuracy is adequate

R_1 = 5 k wire wound
R_2 = N.T.C. 2 k (25° C)
R_3 = 100 Ω carbon
R_4 = 1 MΩ
R_5 = 200 Ω
R_6 = 2·5 k
R_7 = 5 k
C_1 = 0·1 μF paper
C_2 = 16 μF electrolytic
V = 12AU7
P = Electrolytic potentiometer
M = Elliott 0·2 mA per recorder

A second method of applying the electrolytic potentiometer for physiological recording purposes is made possible by the fact that this type of potentiometer has an extremely low mechanical impedance. By using two electrolytic cells in a bridge circuit, one cell being connected to the source of movement which is to be recorded and the other being operated by a suitable electrical drive so that it balances out the imbalance in the bridge, it is possible to use a system with almost 100% electromechanical feedback and so eliminate entirely the need for stable voltages or stable gain in the amplifier. A circuit using this principle is shown in Fig. 4. This is a battery operated unit intended for portable equipment, the source of power being a 6 V nickel–cadmium accumulator. A synchronous vibrator *VB* is used to generate alternating current, the output being supplied *via* T_1 to the bridge circuit consisting of two electrolytic potentiometers P_1 and P_2. Potentiometer P_1 is connected to the moving arm of a recording milliammeter *M*, the exploring probe being attached to the arm just above the writing pen, while the potentiometer itself consists of a Perspex vessel fitting behind the arm on the recording instrument; P_2 is a cell similar to that shown in Fig. 1 and its exploring electrode is attached to the source of movement. The arm of P_1 is grounded, and is, in fact, connected to the grounded side of the meter coil. The voltage on the exploring electrode of P_2 is amplified by a transistor amplifier employing two OC71 transistors, VT_1 and VT_2, as voltage amplifiers and push-pull class B OC72 transistors, VT_3 and VT_4, as power amplifiers. A certain amount of feedback is applied to the circuit to improve its frequency response at the low end. The output transformer of the amplifier is intended to match a 10 kΩ load and is thus not entirely suited for the purpose of this instrument, but it happened to be available. Two resistors across the output of the transformer form a divider, the centre of which is earthed. The two ends of the transformer secondary are connected to the synchronous rectifier contacts of the vibrator, the centre contact being connected to the meter, the arm of which balances P_2. The synchronous rectifier thus acts as a phase-sensitive detector indicating the direction of imbalance of the bridge circuit P_1, P_2. If there is an imbalance in the circuit the meter moves to bring the exploring arm of P_1 to a position which reduces its voltage to zero. The spring of the movement of the meter is set so that the instrument has a centre zero. This means that an imbalance current of ±1 mA is required to bring the bridge to balance at extremes of movement of the exploring electrode of P_2. Because of the relatively high gain of the system an output current of 1 mA does not represent a serious errc Using an 0–2 mA Elliott pen recorder, the system as describe was found to be quite satisfactory for many purposes. Tl variations in contact potential and resistance of the rectifie however, produce a small amount of "jitter." By employin a small paddle on the exploring arm it is possible to ad damping to the movement of the meter and thus to stabili the system.

For more precise work there are a number of alternati circuits. For example, instead of using the synchrono rectifier contacts of the vibrator as a phase-sensitive rectifie a germanium diode ring modulator could be used, thu eliminating the instability at the rectifier contacts. Fo laboratory applications, where the operation of the instr ment from a battery is not necessary, a simple vacuum tut amplifier could be used and a double output triode such as type 6N7 used as a phase-sensitive rectifier to supply th current to the meter. By using a true a.c. meter as a record it would be possible to make the meter itself phase sensitiv by supplying one coil from a reference voltage and the othe from the output of the amplifier.

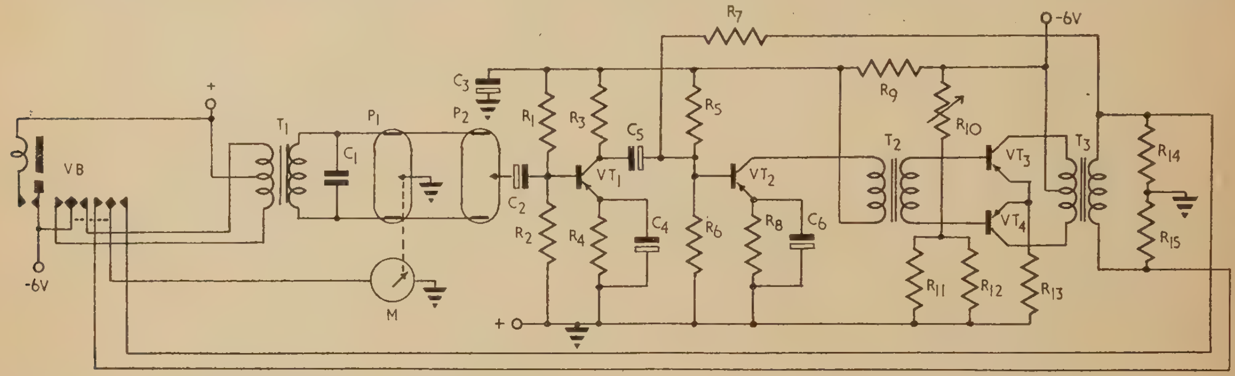

Fig. 4. Circuit diagram of servo-recorder using two electrolytic potentiometers in a bridge circuit

R_1 = 82 kΩ carbon
R_2 = 15 kΩ carbon
R_3 = 5·6 kΩ carbon
R_4 = 1·8 kΩ carbon
R_5 = 39 kΩ carbon
R_6 = 18 kΩ carbon
R_7 = 1 MΩ
R_8, R_9 = 470 Ω carbon
R_{10} = 3 kΩ variable
R_{11} = 82 Ω carbon
R_{12} = 130 Ω (25° C) N.T.C.
R_{13} = 1·7 Ω carbon
R_{14}, R_{15} = 20 kΩ carbon
C_1 = 4 μF paper
C_2, C_3 = 100 μF electrolytic
C_4 = 16 μF electrolytic
C_5, C_6 = 100 μF electrolytic
VT_1, VT_2 = OC71
VT_3, VT_4 = OC72
VB, P1, P2, M—See text
T_1 = vibrator transformer 6 V input, 36 V output
T_2 = interstage coupling transformer
T_3 = the output transformer in this circuit was intended to match a 10 kΩ load and so is not entirely suited for the purpose. However, a satisfactory performance was obtained with it

The advantages of servo-systems are very well known They eliminate the need for the stabilization of gain or o voltage, and the accuracy is dependent only on the mechanics of the measuring system and the sensitivity of the amplifier This makes it practical to use battery operated equipmen without the problems which arise due to voltage changes as batteries age. The electrolytic potentiometer makes it possible to use any recording meter as a feedback device The meter in effect acts as the balancing motor and, provided the gain of the system is high enough, the error caused by the current required to sustain the movement of the meter may be neglected. Because the meter is driven in both directions by the current from the rectifier, much faster responses than are normal for the meter movement may be obtained. In the event of a rapid change in the position of the arm of P_2, the meter is instantaneously overloaded in a sense which drives its arm back to balance.

PRACTICAL USES

The electrolytic potentiometer principle has been in use for three different purposes over the past few months. In all cases it has proved most satisfactory.

(1) As a transducer fitted to a spring balance for the

pose of plotting weight/time curves during the experi-
ntal milking of goats. The cell in this case is a vertical
inder of Perspex with two stainless steel disk electrodes,
top one being perforated in the middle. The distance
ween the disks is adjustable for calibration purposes and
of the order of 1 cm. The probe is a stainless steel wire
ulated by a polythene sleeve and attached by a Bakelite
n to a balance. The amplifier used is of the cathode follower
e driving an Elliott 0–2 mA recorder through a germanium
de bridge rectifier. The 6 V, a.c. applied to the cell is
m a regulated supply.

The chief advantages of this system are:

a) no friction is introduced into the movement of the
balance by the transducer;
b) it is very reliable and easily calibrated;
c) it is a cheap form of remote recording system.

e recorder is set up in the laboratory while the goats are
lked nearby.

(2) For intramammary pressure measurements in cows
d goats. Again the cathode follower amplifier system is
ed with an Elliott 2 mA pen recorder. The transducer is
the form of a horizontal Perspex cylinder of the type
own in Fig. 1. The arrangement of an electrolytic potentio-
eter suitable for the recording of pressure changes of the
der of 0–10 in. of water is shown in Fig. 5. The circuit
scribed in Fig. 2 is employed in this case. A simple lever
plifies the movement of the bellows and so produces a
atively large movement of the exploring electrode. This
stem has proved to be more reliable and much cheaper than
rlier equipment employing a differential transformer,
bilized oscillator and stabilized amplifier. It is also much
aller and lighter, thus reducing the difficulties of handling
ch equipment in the cowshed.

(3) For intramammary pressure changes in small animals
the laboratory. The transducer in this case is a small
rizontal Perspex cell with a rubber diaphragm to move a
ry light probe. The servo-motor version of the system is
ed in this case, the feedback being obtained from a Perspex
ough forming a second electrolytic potentiometer on the
liott meter. While essentially a laboratory set-up, this
stem is reasonably robust and can be made sensitive to
all pressure changes—a full-scale deflexion for a pressure
e of 1 in. of water being quite practicable. Its main
vantage is its speed of operation. Sudden pulses of pressure will move the pen of the recorder much faster than occurs with a normal amplifier because the recorder is momentarily overloaded when the electrical system is out of balance. This overcomes the difficulty inherent in pen recorders with a fair degree of internal damping when used to record rapid changes.

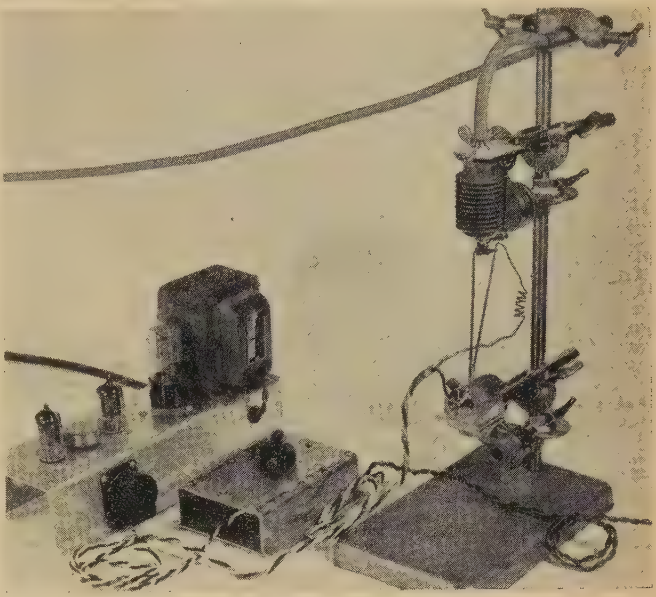

Fig. 5. Arrangement of electrolytic potentiometer suitable for the recording of pressure changes of 0–10 in. of water

ACKNOWLEDGEMENT

The writer is indebted to Mr. J. D. Allen of this Station for making the electrolytic cell and associated equipment which is described above, to Mr. B. H. Millar for the circuit diagrams, and Mr. D. H. B. MacQueen for the photographs.

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Improved Lyman-continuum flash-source of large aperture

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Some of the difficulties attending use of earlier "Lyman flash-tubes," as background sources for vacuum-ultra-violet absorption spectroscopy, have been mitigated or removed in a design employing a 1 cm bore constricting tube. The successful features of the device described have resulted from use of capacitors of high resonant frequency, the design of a discharge-tube of low inductance, and avoidance of a series spark-gap.

INTRODUCTION

bsorption spectroscopy in the vacuum-ultraviolet, below
00 Å, is often rendered difficult by lack of fully satisfactory
urces of background continua. Until quite recently the
urces available were restricted to:

(*a*) An uncondensed positive-column discharge in hydrogen; H_2-continuum, of useful range 1650 Å upwards.

(*b*) A mildly condensed discharge in clean helium; He_2-continuum, of useful range 600–900 Å.

(*c*) A violent pulsed discharge of high current-density; "Lyman continuum," of useful range from a few hundred Å upward.

Continuously running sources, of which (*a*) and (*b*) are typical, have been very valuably supplemented by recent work on continua emitted by the inert gases neon through xenon.(1–5) Though the present writer can claim no direct experience of these new inert-gas discharge-tubes, the published descriptions suggest that, while the xenon and krypton continua are of great value for the range above 1250 Å, use of the neon and argon sources, which yield continua extending a few hundred Å above 744 Å and 1070 Å respectively, involves the difficulty that rather high pressures of pure inert-gas are demanded.

On grounds which can be judged from these remarks, extensive use has, in the past, been made of sources of type (*c*), i.e. "Lyman flash-tubes," which still have certain virtues for vacuum-ultra-violet absorption work, even in face of the discovery of the new inert-gas continua mentioned. The relative merits of the sources, as they appear to the writer, are summarized later. It is worth remark that high-brightness Lyman flash-sources have applications other than to far-ultra-violet absorption spectroscopy; for example, the tube designed by Garton(6) has been used in attempts to determine reversal-temperatures of arc channels.(7)

Flash-tubes suitable for producing the Lyman continuum operate by the impulsive release, through a gas at low static pressure, of energy stored on a capacitor bank, commonly of up to a few microfarads, charged to potentials ranging from a few to a few tens of kilovolts, the discharge path being constricted by a narrow bore tube of fused-quartz, alumina or other refractory. The important parameter for the appearance of a strong continuous emission spectrum is the current-density. At lower values $(\sim 10\,000\ \mathrm{A\ cm^{-2}})$, the spectrum is predominantly line-type and the source brightness is low. With current densities around $30\,000\ \mathrm{A\ cm^{-2}}$ the source becomes of dazzling brilliance and the emission is predominantly continuous, if the discharge path be of the order of a few centimetres in length. According to Anderson(8) who made a careful study of flash continua in the visible region, the use of much larger current-densities gives little gain in intensity.

When such a flash-tube is to be used as a spectroscopic source, the constricted discharge is presented "end-on" to the spectrograph slit. Hitherto, the constricting tube itself has suffered rapid erosion from the violence of the capacitor discharge—in typical cases, milligramme quantities of wall material being removed in each pulse. A series spark-gap has almost invariably been inserted between storage capacitor-bank and discharge-tube in order to control the potential applied, and hence the energy released in each pulse. The nature of the carrier-gas is rather immaterial, so far as concerns the intensity and its distribution over the continuum, as is also the static pressure. However, for vacuum-ultra-violet work, helium has the advantage of transparency to short wavelengths.

Of the several detailed designs of Lyman flash-tube described to date, the following have embodied successive improvements in performance, convenience and speed of operation. Collins and Price(9) employed a tube having advantages of simplicity and ease of replacement of eroded quartz capillaries, which were of 1–2 mm bore. Improvements, notably in preventing rapid contamination of the spectrograph slit by discharge debris, were contained in a design due to Worley.(10) Worley's tube was further developed by Garton,(6) who also, by use of larger stored energies, found it feasible to work with constricting tubes of 5–6 mm bore. Very recently a neat design, again using narrow bore ceramic tubes, has been described by Greiner.(11) Finally, a novel construction has been given by Romand, Balloffet and Vodar.(12)

All these sources of Lyman continuum have been recognized to have the following drawbacks in common. Thou the continuum is of very high intensity, and, in the regi above 1800 Å, is fairly free of overlying emission and abso tion lines, these undesirable features form an increas nuisance as we proceed to shorter wavelengths. These li arise partly from the carrier-gas and its impurities, b chiefly from the first few stages of ionization of the eleme introduced into the discharge channel by evaporation of t wall of the constricting tube. Thus, commonly SiI and S lines appear in absorption, SiIV, OV and OVI in emissio and so on. When the Lyman continuum is used as a bac ground, the absorption lines arising in the flash-tube its are, of course, particularly objectionable, in making diffic the recognition of real absorption lines or bands of weak diffuse character.

Other drawbacks resulting from rapid erosion of the tu wall are the necessity of frequent replacement and the co tamination of slit or window, though the latter trouble h been partially mitigated in Worley's(10) design. Again, u of the Lyman continuum as background for quantitati intensity work has been precluded by lack of intensi reproducibility from one flash to the next. Finally, if th source is of small aperture, alinement on the spectrograp axis becomes troublesome, and, in cases where it is necessa to insert the absorbing gas between light-source and slit, th light-flux through the latter is small, so that frequently so hundreds of successive flashes have been reported necessar to record an absorption spectrum. Some of these di advantages have been lessened or removed in the new ty of flash-source described below.

PRINCIPLE OF CONSTRUCTION

It seems that, in all forms of Lyman flash-source previous used, slight effort has been directed to making the tube an the associated electrical circuit efficient, in respect of max mum instantaneous power. Indeed, it is doubtful whethe pending quite recent improvements in high voltage capacito design, much could have been done in this way.* Tw obvious steps in the required direction are, (*a*) to reduce th inductance of the capacitor bank, the connexions and th discharge-channel itself, and (*b*) to avoid energy waste in series spark-gap.

Possibilities of advance in direction (*a*) recently appeare promising, following the acquisition of a number of capacitor each of 1 μF, 7 kV working, of small dimensions, and havin a residual inductance stated by the makers to be of orde 50 mμ H. The capacitors are also of such low cost as t make them reasonably expendable. Their existence gav impetus to a re-design of the discharge-tube itself, in th form of a co-axial conductor, joined to the capacitor ban by connexions of negligible inductance. In this way it ha been possible to construct a source, run from 8 μF at 7 kV in which the discharge constriction is performed by a one centimetre bore refractory tube. The source gives a stron continuum, with useful intensity extending down to at leas 350 Å, practically free of overlying absorption lines, an much less affected than the continua of earlier tubes b superposed emission lines. The whole assembly is compact easily aligned and appears to require very little attention.

Detailed studies of optimum working conditions, including me-resolution studies of electrical characteristics and spectra ave yet to be made. However, the practical advantages of e source, as at present developed, are thought to be ufficiently considerable to justify the following description f its construction.

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* An important paper by Fisher(13) is concerned with short sparks in gases at or above atmospheric pressure. Though his arrangement differs in form and purpose from the Lyman Flash-tube, Fischer's work partly inspired the re-design of the latter type of source here reported.

CONSTRUCTIONAL DETAIL

The constructional details of the present form of the source can be understood from the overall front- and side-views of Figs. 1(*a*) and (*b*), the detailed section of the discharge-tube proper in Fig. 2(*a*), and from Fig. 2(*b*), which

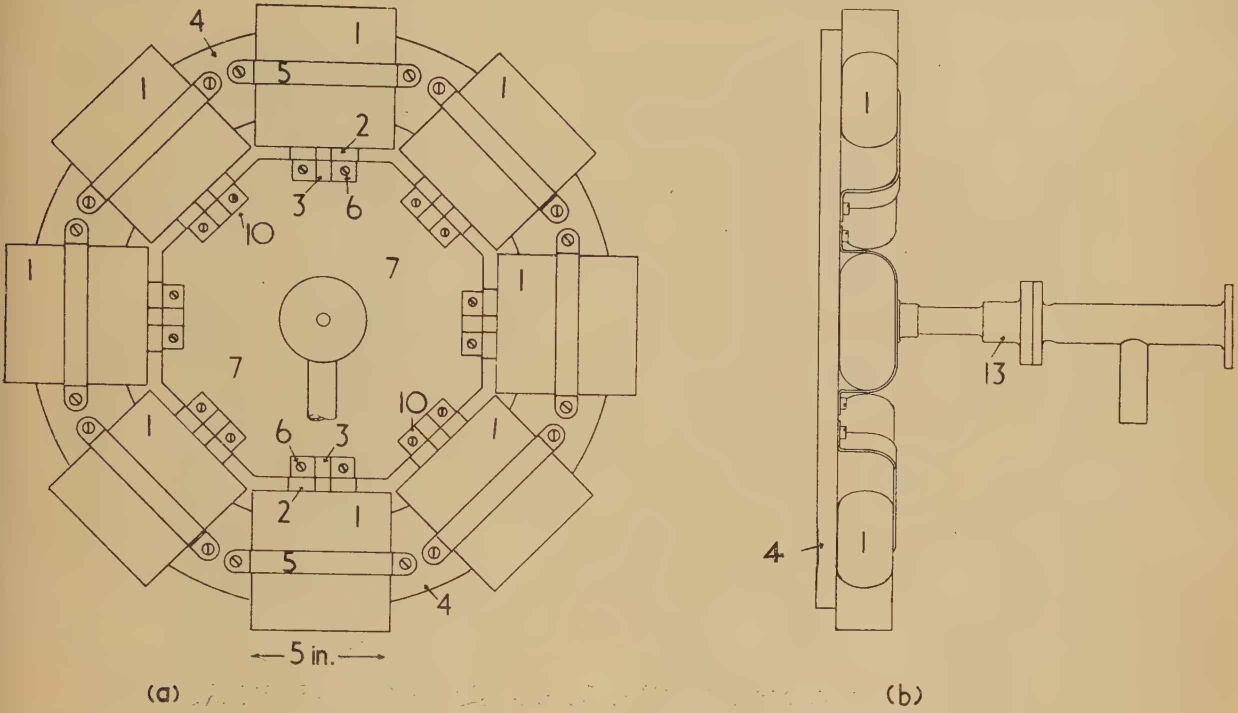
4
1
5
2
3
6
10
7
1
13
4
5 in.
(a)
(b)

Fig. 1. Overall construction of the Lyman flash-source
(*a*) Front elevation, (*b*) side elevation.

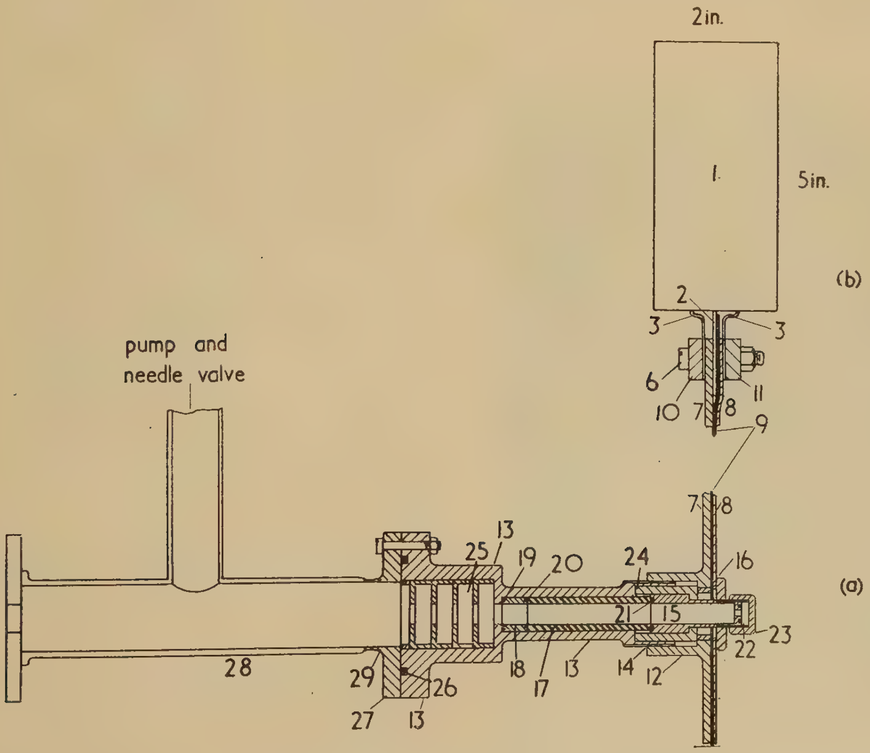
2in.
1
5in.
(b)
2
3
3
6
10
7
8
11
9
pump and needle valve
7
8
13
25
19
20
24
16
21
15
23
22
28
29
26
27
13
18
17
13
14
12
(a)

Fig. 2. Lyman flash-source
(*a*) Detail of discharge tube, (*b*) connexion of capacitor.

shows the manner of connexion of one of the capacitors used.

Each capacitor is of "bobbin-wound" pattern, with jelly impregnated paper insulation, the bobbin being protected by a cardboard case filled with wax. Rigidly attached to the body of the capacitor 1, and projecting through the wax, is a piece of $\frac{1}{16}$ in. thick paxolin sheet 2, on opposite sides of which the aluminium foil leads 3 are brought out.

The eight capacitors 1 are mounted on a wooden hoop 4 by means of metal straps 5 [Fig. 1(*a*)]. Supported on the paxolin projections 2, and held by means of screws 6, is a so-called "disk transmission line," composed of octagonal copper plates 7 and 8, respectively of $\frac{1}{8}$ in. and $\frac{1}{32}$ in. thickness, which are separated by a piece of 0·020 in. P.V.C. sheeting 9. The P.V.C. sheet extends slightly beyond the outer edges of the copper plates, as shown in Fig. 2(*b*). The 4 B.A. screws 6 penetrate both copper plates 7 and 8, the P.V.C. sheet 9 and the paxolin 2, and, by means of Perspex blocks 10 and 11, clamp the capacitor leads 3 to the copper plates 7 and 8. To prevent the screws 6 from short-circuiting 7 and 8, a hole $\frac{1}{2}$ in. in diameter is cleared around each screw 6 where it penetrates the conductor 8, and to prevent spark-over between 6 and the edge of this hole in 8, paraffin-wax is melted into the shallow annular space thus formed between Perspex block 11 and the P.V.C. sheet 9.

The discharge-tube proper is built, as shown in Figs. 1(*b*) and 2(*a*), in the form of a co-axial extension of the octagonal-plate transmission-line, the plates 7 and 8 of which have central holes respectively 1 in. and $\frac{7}{8}$ in. in diameter, the corresponding hole in the P.V.C. sheet 9 being $\frac{1}{2}$ in. Sweated to conductor 7 is a short copper tube 12, threaded internally. The earthed negative electrode 13 of the discharge-tube is turned from a single piece of aluminium, and screws into 12 at 14. The high-potential positive electrode 15 is also turned from aluminium, and carries a large knurled nut 16 which bears against the conductor 8 and provides electrical contact.

The discharge constriction is performed by a piece of alumina refractory tubing 17, of 1 cm bore, 5 cm length and about 3 mm wall, which is clamped firmly between the en of the hollow anode 15 and a thick aluminium washer 1 Silicone rubber O-rings 19, 20 and 21 render the discharg tube vacuum-tight. The purpose of the washer 18 is to avo necessity of sinking an O-ring groove in an inaccessible pla inside 13. The back of the anode 15, on the right in Fig. 2(*a* is closed by a small glass window 22, held against an O-rin by a screwed collar 23. To prevent spark-over between th electrode 15 and the edge of the conductor 7, polythen bushing 24 is inserted. Inside the enlarged forward end the cathode 13 are accommodated three or four baffles 2 each of which has a central aperture of some 9 mm. Thes baffles have been found essential in stopping the forwar ejection of discharge debris. The front end of 13, which grooved for an O-ring 26, is attached to a metal flange 2 which carries a glass extension piece 28 by means of a meta glass seal 29.

It will be realized from the foregoing that the transmissio line 7, 8, 9 is clamped together by the screws 6, and als between the nut 16 and the anode 15 together with polythen bushing 24. The remainder of the discharge-tube the screws, by way of the cathode 13 and the screw-thread in 1 down on to the O-ring 21. Although, for sake of clarity the feature has been omitted from the diagrams, the plates and 8 are further pulled together by a number of insulate screws spaced about half-way between the screws 6 and th centre of the plates. In Fig. 3 a photograph is reproduce of the assembly, except for the glass extension 28; in th left foreground one of the capacitors used can be seen.

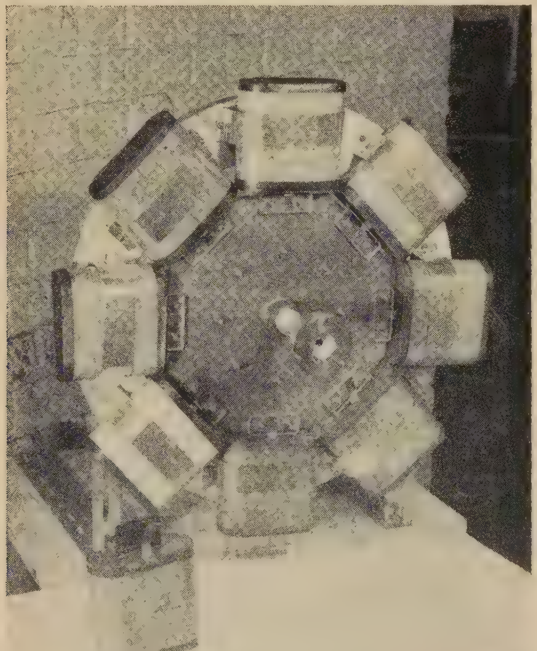

Fig. 3. Assembled discharge tube and capacitors

OPERATION AND PERFORMANCE

The method of operation of the flash-source, so far adopted has been as follows. The forward end of the glass extension 2 being closed, either by a window or by attachment to th slit of a vacuum spectrograph, the tube is exhausted by small diffusion-pump. The capacitors are charged from rectifier to 7 kV, and the discharge is then initiated by quick slight twist of a needle-valve, inserted in the pumping line and providing a supply of commercial helium. By us of the diffusion pump to reduce the static gas pressure to the point where the tube will withstand 7 kV, the introduction of a series spark-gap is avoided.

With alumina tubes 17 of the size stated, the spectrum a 5 kV, shows a fairly large number of emission lines as wel as underlying continuum, over the whole range from visible to vacuum-ultraviolet. The lines are much less obtrusive a 6 kV, and hardly in evidence at 7 kV, at wavelengths above 1550 Å; short of this wavelength the emission lines become stronger relative to the continuum. Of the very few absorption lines to be seen throughout the whole range down to 350 Å, the 1216 Å line of hydrogen is amongst the strongest. Using a 1 m normal-incidence vacuum-spectrograph, having an unblazed f/25 grating ruled with 600 lines/mm on speculum metal, the continuum has been photographed at good intensity down to 500 Å on a type Q2 plate (by Ilford Ltd.), with only ten to twenty flashes. Fig. 4 illustrates the use of the continuum in registering the absorption bands of oxygen and nitrogen in the short-wavelength ultraviolet.

As indicated below, each light-pulse is probably of the order of 2 μs duration, so that the light-flux at the slit is very high, even at short wavelengths. The continuum intensity is observed to drop rather sharply below 500 Å. This may be in part due to falling reflectance of the speculum grating but, more probably represents onset of the fairly strong photoionization continuum of the helium used.

levertheless, useful intensity has been obtained to 350 Å, elow which the grating used is very inefficient.

In course of development of the source, constricting tubes f bores ranging from a few millimetres to 15 mm of both used quartz and alumina refractory have been tried. Rather urprisingly the quartz tubes have been found markedly nferior, owing to tendency to shatter readily. The implicaion seems to be that the shattering of the tubes results from nechanical rather than thermal shock, since, of the two naterials, quartz is supposed to have the higher thermal hock resistance.

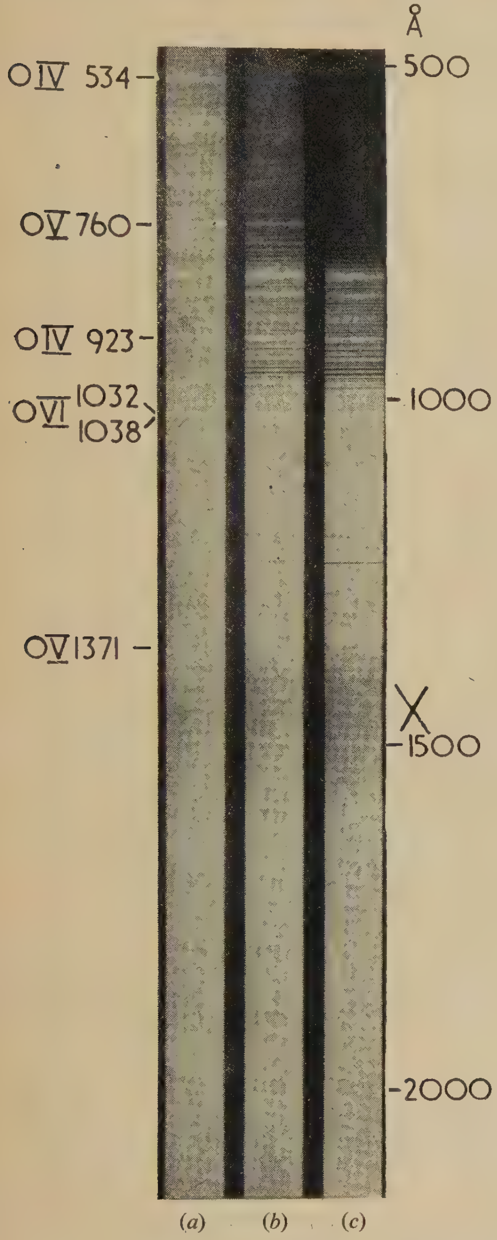

Fig. 4. Air absorption bands on Lyman-continuum background

(a) Spectrograph pumped hard, (b) and (c) slow air current in spectrograph at two different pressures.

The absorption X is due to the oxygen Schumann–Runge continuum.

Though an alumina tube of the size now used, that is, 1 cm bore, shows signs of crazing on the inner surface after a little running, the wall erosion must be very slight, and it appears that one tube will have a very long useful life. Correspondingly, the difficulties attendent on the forward ejection of wall material towards slit or window are reduced. An interesting observation in this respect is the following. When the flash-tube was tested without the baffles 25 inserted, a window at the end of 28 rapidly acquired a heavy deposit, while, with baffles in position as shown in Fig. 2(*a*), which obscured the mere edge of the alumina tube 17, projection of wall material was made negligible. This suggests that the wall material is ejected, if the baffles are omitted, in the form of a hollow jet, most of it no doubt settling on the curved side of 28, but sufficient reaching window or slit to give trouble. Whether this explanation is correct or not, the practical result is that adequate baffling can be achieved without any appreciable loss of linear aperture of the light source.

Though as yet no detailed time-studies have been made of light-output or current, a consistent estimate can be made of the likely current and pulse duration. The inductance of the discharge-tube is easily calculated, on the assumption that the whole cross-section of the constriction conducts. The inductance of the transmission-line is negligible, and that of the capacitors can be taken to be as stated by the makers. We thus estimate the total inductance to be of order 2×10^{-8} H; the capacitance is 8 μF, so that $2\pi\sqrt{LC}$ is of the order of 2 μs. It is not known whether the discharge is oscillatory, though if so the damping will be very rapid. Nevertheless, the mean current, for a 2 μs pulse, will be of the order of 28 000 A and, again assuming that the discharge fills the whole constriction, a mean current-density of approximately 37 000 A cm^{-2} is indicated. This figure is of the correct magnitude for appearance of a strong continuous emission, according to Anderson's observations.(8)

SUMMARY

Some appraisal of the relative merits of the improved source of Lyman continuum described and the several sources of inert-gas continua referred to in the Introduction, seems appropriate here.

For absorption studies in the region below 600 Å, the flash-tube is the sole available source, if we except the electron-synchrotron, usually difficult of access. In the region 600–850 Å the He$_2$-continuum is easy to generate and practically free of interfering lines; above 850 Å it becomes rather overlaid by lines due to impurities difficult, if not impossible, to remove completely. Hence, in the range 850–1250 Å a well-run flash-tube is again probably the most convenient background source, for much work, with possible rivalry from argon and neon continua(5) in special cases. Above 1250 Å krypton, xenon and hydrogen continua are likely to be, for most purposes, better general backgrounds. For absorption studies of brightly luminous gases the flash-tube becomes essential.

Several further improvements in and possibilities of the arrangement described suggest themselves. For work on absorption spectra of brightly luminous gases,(7) it is necessary to "gate" the spectrograph slit, and to fire the flash-tube during a brief interval while the slit is uncovered. The simple "gas-pulse" method used as described above will, in this case, have to be replaced by use of an additional triggering electrode, to which a high-voltage pulse can be applied. Such a technique would appear to face no serious obstacle.

There is room for hope that the arrangement described in this paper may assist quantitative work on absorption coefficients of gases in the vacuum-ultra-violet. Many measurements of this kind have been made over the last ten years, but, because of the lack of reproducible background continua in the appropriate spectral ranges, it has been usual to employ sources providing line-emission,(14, 15) and it has been recognized that this may result in important detail being missed. It is possible that in the present design of flash-source the major obstacles to intensity reproducibility from flash to flash have been overcome, since, in the past, these have arisen from the effects of wall erosion and irregularities due to use of a series spark-gap. The paper of Po Lee and Weissler(14) may be referred to in the latter regard.

Whether, as is certainly possible, it will be advantageous to reduce still further the residual inductance of the capacitors is a problem which must await the results of time studies of the discharge phenomena.

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I am glad to acknowledge help received from the Wego Condenser Co., Perivale, Middlesex, acting through Dr. F. C. Stephan, and Mr. D. P. Downey, for advice and co-operation leading to provision of the compact high resonant-frequency capacitors which were essential to the success of this light source. Thanks are due also to Messrs. T. Shand and F. Schofield, of the Physics Department Workshop at this College, for skill in construction an patience during mastery of the inevitable teething troubles.

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X-ray analysis technique for very high temperatures

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A new powder-diffraction technique for very high temperatures is described, in which a thermocouple combines the functions of sample support, heating, and temperature measurement. This device is simple, compact and inexpensive, and has proved to be very reliable. The maximum working temperature depends on the thermocouple material, and is normally 1750° C using 5/20 rhodium–platinum, or 1850° C with 20/40 rhodium–platinum couples.

Recording X-ray powder diffraction patterns at temperatures over 1400° C raises difficult problems in camera and furnace design. In a confined space provision must be made for sample mounting, heating and temperature measurement, without causing overheating of the camera or interruption of the X-ray paths. Usually this means constructing special cameras of varying complexity, of which several examples have been described for ceramic or metallurgical applications.(1–6) For ceramic materials one of the simplest techniques(7) is to coat the sample on a platinum wire support which is heated electrically, the power consumption giving a rough indication of the sample temperature. As heat dissipation is not excessive, existing cameras may be adapted fairly readily to this technique, but rotation of the sample is difficult to arrange. The major drawback is that the wire temperature is only known with accuracy after the exposure, from the measured lattice expansion of the platinum lines on the film. Even so it does not follow that the sample temperature will be the same as that of the wire, as large temperature gradients are produced by radiation losses. These limitations are overcome by a new technique of comparable simplicity, derived from a microscope hot-stage design. As this hot-stage design has already been described,(8) only the modifications required for X-ray diffraction will be described in detail.

NEW TECHNIQUE

The essential feature of the hot-stage is the direct mounting of the sample at the tip of a small thermocouple which registers its own temperature. This arrangement obviates the calibration difficulties, discussed by several authors,(9–12) that are inherent in many camera designs where there is no direct contact between the sample and the temperature-measuring device. The sample is heated by passing a 50 c/s current through the thermocouple. A synchronous switch, phased to the supply voltage, isolates the thermoelectric current from the heating current by allowing unidirectional pulses of heating current to flow only during alternate half-cycles. In the intervening half-cycles the thermocouple is connected to the temperature-measurement circuit. The sequence of operation is sufficiently rapid to maintain the sample at a steady temperature which can be measured by a potentiometer or deflexion instrument.

The arrangement is simple and compact, and could be incorporated in many existing Debye–Scherrer cameras without introducing problems of overheating. The ease with which thermocouple-heaters and samples can be exchanged, and the almost negligible cost and effort of renewal in the event of "furnace" failure, are also attractive features. Furthermore, the required temperature is obtainable and measurable instantly, eliminating operational delays. The lisadvantages will be more easily understood if discussed ifter describing the sample holder.

SAMPLE HOLDER

This is illustrated in Fig. 1 (lower right) and was designed pecifically for use in either microscope or X-ray camera. For X-ray use the guide pins required for microscope use ire removed. Electrical connexions are made by a removable ocket connector, mating with brass pins insulated from the ase. The terminations of the pins are made to grip wire upports of 5% rhodium–platinum and 20% rhodium–latinum alloy. These wires, 0·5 mm diameter and approxinately 25 mm long, are welded in an oxy-coal-gas flame to eater wires of the same alloys, 0·2 mm diameter and 8 mm ong. The free ends of the fine wires are lightly welded ogether to form the thermojunction. The shape and size f the junction have an important bearing on the temperature niformity of the sample. The use of a special cutting tool Fig. 1, left) eliminates variations from this cause, and educes the making of a satisfactory junction to a routine peration.

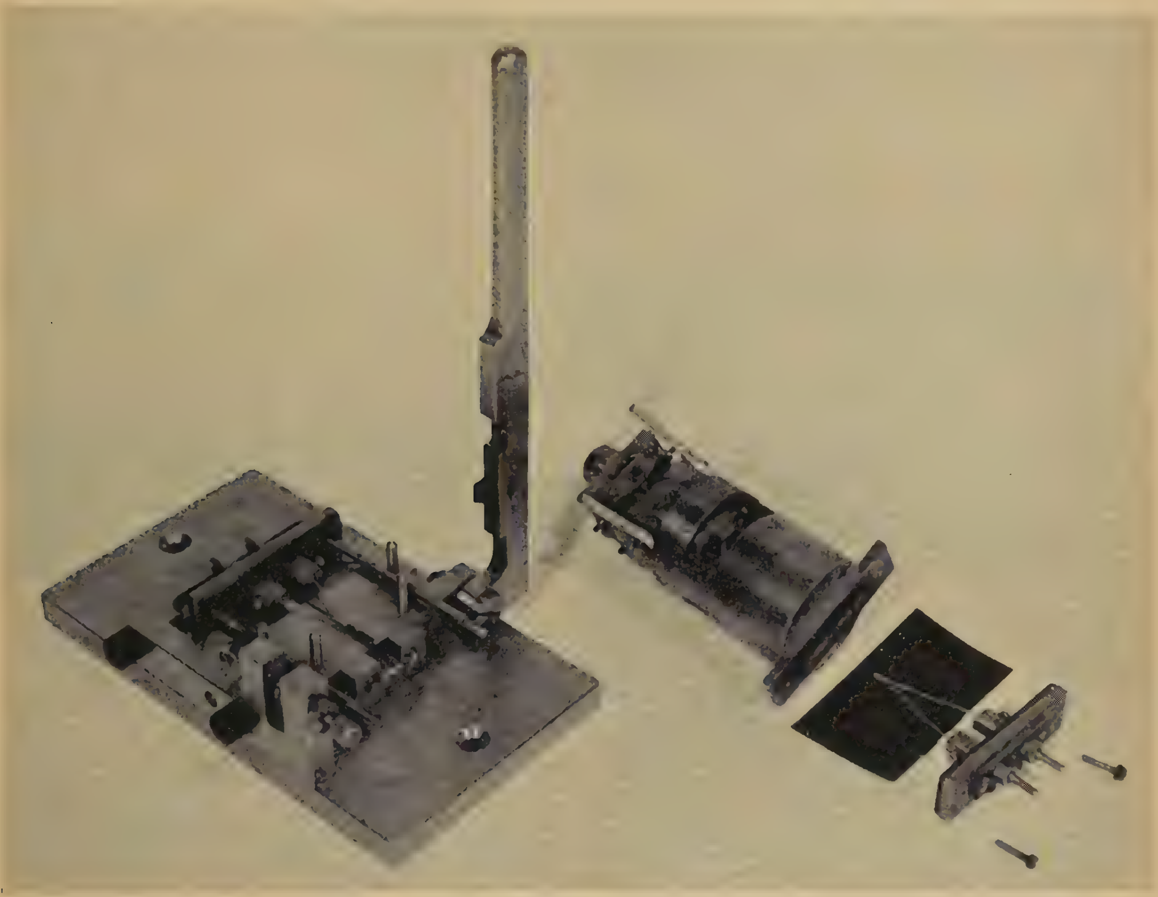

Fig. 1. (*left*). Combined jig and cutting tool for preparing thermocouples. Sample holder in position with guide pins for hot-stage microscopy still attached. (*Upper right*): Gas enclosure with window material removed and base exposed, showing goniometer arcs and gas connexions. (*Lower right*): Sample holder with guide pins removed for X-ray use. A neoprene gasket forms a gas-tight seal with the gas enclosure base

The tool is provided with a jig to assist in cutting the eater wires to the required length before welding, and the velded junction is reduced to a constant thickness of 0·2 mm by a guillotine knife. A slip gauge ensures a uniform spacing of 0·2 mm between the wires close to the junction where the sample will be placed. The operation of shaping the heater wires must be done without straining the supporting wires, otherwise the heater wires will tend to spring apart at high temperature. The heater can be used in any position, but vertical operation, with the junction uppermost, gives the best results.

The thermocouple material was chosen for several reasons. It gives an almost linear output of some 10 μV/° C between 1300 and 1800° C. The output falls off abruptly towards room temperature, so that cold-junction corrections may be ignored. The 5/20 rhodium–platinum couple remains very stable in calibration when heated alone or in contact with many ceramic materials for long periods at high temperatures. It deteriorates gradually through oxidation and subsequent volatilization when heated in air, but in a neutral environment it remains apparently unaffected.

Allowing a reasonable working margin within the melting point of the 5% rhodium–platinum alloy a maximum working temperature of 1750° C should be possible, although 1700° C has not so far been exceeded with this type of thermocouple. A few exposures have been made at 1850° C using a 20% rhodium–platinum/40% rhodium–platinum couple, which gives an output of only 4 μV/° C at high temperatures but otherwise shares the characteristics of the 5/20 rhodium–platinum couple. A tungsten–molybdenum couple may be heated to about 2500° C in an atmosphere free of oxygen and water vapour, and, although this couple is attacked by melts at high temperatures, it might be suitable for X-ray powder work above 1850° C.

LIMITATIONS OF THE TECHNIQUE

Apart from the probable restriction to non-conducting materials, the chief disadvantage is the screening of the sample by the heater wires. However, as Fig. 2(*a*) shows, no lines are completely cut off in the case of a sample lying flush with the heater wires in a plane normal to the incident X-ray beam. The presence of the heater wires on either side of the sample effectively increases the sample absorption; consequently, intensities in the transmission region as a whole are approximately halved in relation to those in the back-reflexion region, when compared with the pattern given by a conventional rod-shaped sample [Fig. 2(*b*)]. The heater wires also produce a more intense local screening in the $\theta = 45°$ region. Normally this is unimportant, as the low angles most useful for indexing and the high angles for precise lattice-parameter determination are not affected in this way. If necessary, however, the partially screened region may be displaced from the $\theta = 45°$ position by turning the plane of the specimen a little, and as the screening effect is only prominent when the sample is stationary, a small angular oscillation reduces the effect considerably [Fig. 2(*c*)]. A precise evaluation of the screening effect would be required only in problems where accurate comparison of intensities over a wide range of θ values is essential. The diffraction pattern of the heater wires is unavoidably superimposed on that of the sample, but confusion with the sample is rather unlikely, as a well-aged heater recrystallizes to such an extent that its diffraction pattern degenerates into a few easily recognizable spots.

Recrystallization of a powder sample, leading to spottiness of diffraction lines, is a general problem in high temperature X-ray work that is not peculiar to the present technique. The screening effect of the heater wires, however, indirectly aggravates this problem, since the exposure time must be doubled in order to compensate for the effective increase in sample absorption. As the sample movement is restricted to a limited degree of oscillation, partly by the screening effect and partly by the electrical connexions, other measures for reducing spottiness must be fully exploited. The first step is to grind the sample as finely as possible at the outset. The second is to limit the amount of subsequent recrystallization on heating. For ceramic materials, sintering and recrystallization phenomena are strongly influenced by the presence of water vapour, so that operation in a dry atmosphere helps considerably. Exposure time can be minimized by using fast film, a slit rather than a pinhole collimator and by avoiding the use of too thick a specimen.

MOUNTING THE SAMPLE

Mounting the sample is easy if a binding agent is permissible; with careful handling, however, a binder is unnecessary. If the heater wires are laid on a flat surface, such as a microscope slide, the sample can be embedded between the wires by gentle pressure with the aid of a small flexible spatula. Preparation of the sample in this way takes no longer than the conventional techniques. The powdered sample should form a column about 2 mm long and of uniform width and thickness.

By observing a polymorphic change at 1450° C under the microscope, the maximum temperature difference over a typical sample was estimated as 5° C along the column and 15° C transversely. The overall temperature variation of the sample probably does not exceed limits of ±10° C, as a clear-cut change is obtained in X-ray patterns recorded at a 25° C temperature interval spanning a known phase change. While such a temperature gradient may be too large for the most exacting requirements, it is satisfactory for many applications in the ceramic field.

ATMOSPHERE CONTROL

Provision is made for operating the sample holder in a gas enclosure within the X-ray camera. This arrangement is not obligatory at lower temperatures if the heater wires are

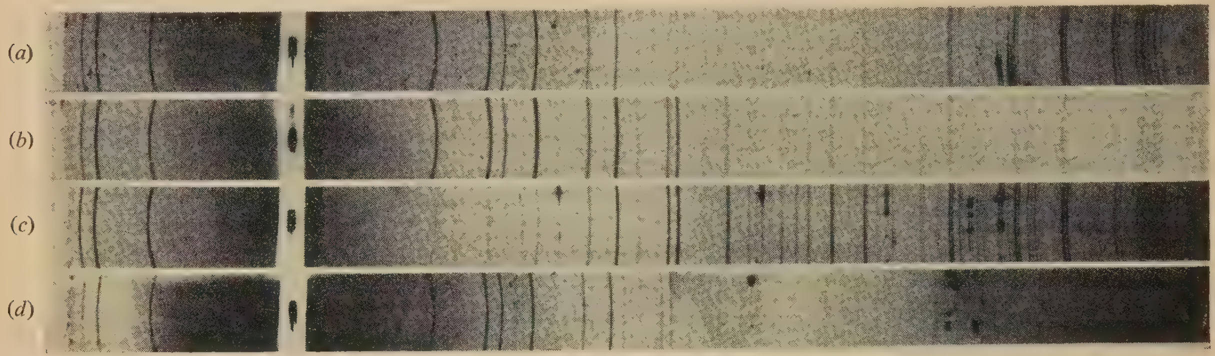

Fig. 2. X-ray photographs of corundum (αAl_2O_3) in 102 mm diameter camera. CuKα radiation, nickel filter, 38 kV, 20 mA

(*a*) Room-temperature film (without gas enclosure) of sample mounted in thermocouple; exposed surfaces of sample lie flush with heater wires in a plane approximately normal to the incident X-ray beam. Sample holder stationary, exposure 1¾ h.

(*b*) Room-temperature film (without gas enclosure) of sample in 0·2 mm cellulose acetate capillary. 90° oscillation range, exposure ¾ h.

(*c*) As (*a*), but sample-holder turned through 38° and oscillated ±8°. Exposure 2 h.

(*d*) High-temperature film (1850°) with sample in gas enclosure. Sample-holder positioned as in (*a*), but oscillated ±8°, exposure 4½ h.

Note the shadow image of the thermocouple in (*a*), (*c*) and (*d*) and the sharpened diffraction lines resulting from the additional collimating effect of the thermocouple wires in these films as compared with (*b*). The heavily spotted arcs in (*a*), (*c*) and (*d*), and absent in (*b*), represent the diffraction pattern of the heater wires.

tected from draughts. At higher temperatures there is an vantage in operating in an inert atmosphere, as sample rystallization is minimized by exclusion of water vapour, l deterioration of the heater wires by oxidation is vented. Oxygen-free nitrogen (British Oxygen Co. /hite Spot"), dried by passage through magnesium rchlorate, has been found satisfactory. The flow of gas is intained at the minimum rate necessary to ensure a sitive pressure within the enclosure, as shown by a bubble licator at the outlet.

The enclosure takes the form of a cylinder, 38 mm external imeter, provided with window openings 12 mm high for try and emergence of the X-ray beams (Fig. 1, upper ht). It is suspended vertically with the sample holder ectly from a goniometer head which is used for centring e sample. The enclosure oscillates together with the nple, obviating the additional gas-tight gland that would ierwise be necessary. Of available transparent window aterials, the most satisfactory results have so far been tained with Styrafoil, 0·025 mm thick (by B. X. Plastics d.) which is sealed to the enclosure with adhesive tape. yrafoil superimposes on the sample pattern only a very oad halo, which is fainter than that produced by cellophane cellulose tape. As the mean heater consumption is only 2 A at 1·1 V when operating at 1850° C, no elaborate oling arrangements are required. At sample temperatures er 1200° C the adhesive tape used for sealing the window aterial becomes warm enough to soften slightly. Sufficient oling to prevent this can be obtained from a small electric n mounted near the camera. The connecting lead between e sample holder and power supply passes through one of e two zones screened by the heater wires, and emerges ongside the goniometer head. This arrangement permits e film holder to be installed or removed from the free end the sample holder at any time without disturbing the ectrical or mechanical connexions.

GENERAL OPERATION

The power supply follows that described in the earlier per,(8) except that a different voltage stabilizer has been troduced to improve long-term temperature stability. is stabilizer (Claude Lyons Ltd., type BAVR 500: input 7–242 V, 47–52 c/s; output 230 V ± 0·15%, 500 VA) fectively reduces temperature fluctuations of the sample to 2° C for variations of ±10 V in the 230 V mains supply. lthough the stabiliser output waveform is much distorted, is has no adverse effect on the synchronous switch if the itial adjustments have been made properly. Once the vitch has been correctly phased with the stabilizer output, e only attention required is a daily check of the contact osure times. For test purposes the equipment has operated liably and without attention for continuous periods of up twenty-four hours.

The new technique has been used mainly in a study of ıase equilibria in the system $CaO–SiO_2–P_2O_5$, for which xposures of three to four hours have been found satisfactory a 10 cm camera using CuKα radiation at 38 kV, 20 mA. uring some 150 exposures, aggregating about 500 hours of peration, the short-term temperature fluctuations have sually been within ±2° C, and long-term drifts have been bout 2° C/hour in either direction. At the highest working mperature so far attempted, a downward drift of 12° C om 1850° C was observed over five hours. Where the mple is easily removed by an appropriate solvent, the sample older may be used repeatedly in an inert atmosphere. At mperatures above 1500° C in air, however, the life of the heater wires is limited, and they should be renewed after each such exposure.

An alternative type of power supply, used by Ordway(13) for high temperature microscopy, should be applicable with equal success to the present technique. With this method of heating the thermocouple by a 5 kc/s current, an inductance-capacity filter is used to segregate the thermoelectric e.m.f. for temperature measurement.

THE CAMERA

The basic instrument used by us at present is a Unicam single-crystal Weissenberg camera. This can be operated in a horizontal position, but vertical operation is preferable as it affords greater protection to the window material from convected heat, and gives the smallest temperature variation over the sample. Furthermore, the goniometer head is less liable to strain when the gas enclosure, which it supports, hangs vertically below it. The height of the enclosure in relation to the sample holder dimensions is such that the sample is located approximately at the centre of the goniometer arcs.

To reduce exposure time and spottiness of diffraction lines, the original collimator was replaced by one having a slit 1·2 mm high and 0·2 mm wide and fitted with a scatter trap. To achieve better resolution, the Weissenberg film holder was replaced by one of 102 mm internal diameter with 3 mm wall that just clears the collimator support. For

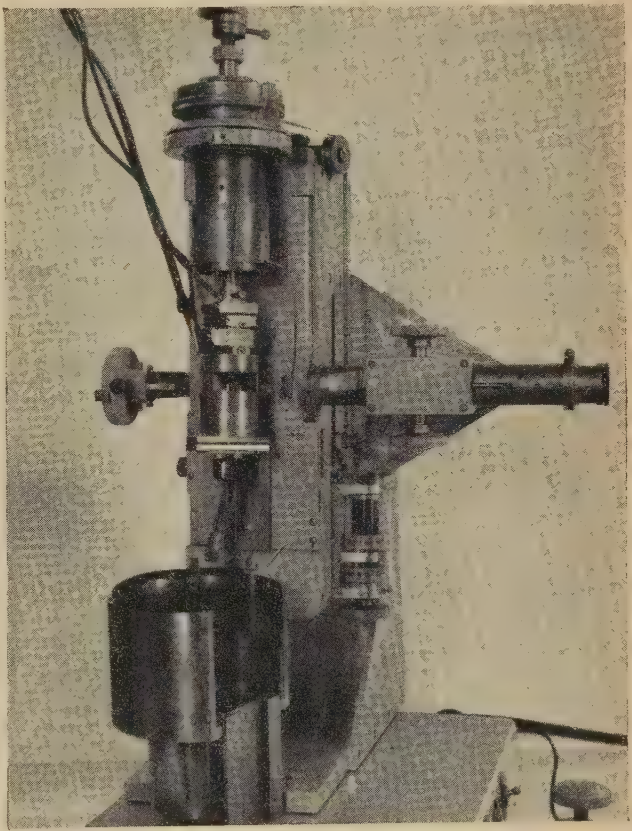

Fig. 3. General view of camera showing heated sample in gas enclosure, with gas and electrical connexions in position but window material removed. The collimator is on the left and beam trap on the right of the enclosure. The film cylinder has been positioned to show the cut-away base and collimator clearance slot

mounting purposes the cylinder carries a concentric extension which is made a push-fit inside a shortened version of the original 57·3 mm diameter film holder. The length of the film cylinder is not critical, depending partly on the dimensions of the gas enclosure and partly on whether it is desired to use a screen to record more than one exposure on the same film. A part of the new film cylinder is cut away because of the small clearance from the base of the Unicam instrument, and a slot is provided to allow removal for film reloading without disturbing the collimator (Fig. 3).

A beam trap, with a piece of fluorescent screen at the bottom, was attached by means of a collar to the boss which usually carries the layer line screen. The thickness of the bottom of the beam trap (about 1 mm thick for 40 kV beam) was chosen so that an image of the primary beam with the shadow of the thermocouple wire is printed on the film during exposure (Fig. 2).

The initial alinement of the sample at room temperature is made by telescope. The final adjustments can be made at the operating temperature either by telescope or by the X-ray beam using a fluorescent screen.

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Calorimeter with automatic control

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The temperature differences between the specimen and its surrounding reference shield in a Smith's(1) calorimeter, modified to operate in a vacuum, is held constant by automatically adjusting the power input to the furnace. Fine adjustment is achieved by a variable reactance in the power supply. The reactance control current is obtained from a single valve d.c. amplifier, the control signal of which is the output voltage of a Wheatstone bridge network containing two photocells. Departures from the desired temperature difference cause a light spot reflected by a galvanometer to move from one to the other photocell, and so adjust the furnace power input and restore the original conditions. Specific heat-temperature curves smooth to within ±0·5% and reproducible within 3% have been obtained between 50–250° C.

A method for determining specific heats has been described by Smith,(1) which allows values to be obtained while heating and cooling. In principle, the sample is surrounded by a solid thermal insulator, which has reproducible heat transfer characteristics. The insulator and sample lie inside a furnace. The chosen temperature difference ϕ between the enclosure and the specimen is held constant during the experiment, and the inverse rates of heating and cooling of the specimen are measured. A duplicate experiment with a copper sample and the same chosen temperature difference enables the apparatus to be calibrated, and by means of the following equation the specific heat of the sample may be calculated.

$$s_1 = \frac{m_2 s_2}{(dt/d\theta)_2} \times \frac{(dt/d\theta)_1}{m_1} \qquad (1)$$

where m_1 = mass of sample, s_1 = specific heat of sample, $(dt/d\theta)_1$ = inverse rate of heating or cooling of sample, m_2 = mass of copper sample, s_2 = specific heat of copper, and $(dt/d\theta)_2$ = inverse rate of heating or cooling of copper sample.

For most purposes it is not necessary to calculate the inverse rate values used in equation (1) because the temperature interval $d\theta$ is approximately constant when chromel-alumel thermocouples are used. Therefore equation (1) reduces to

$$s_1 = \frac{m_2 s_2}{dt_2} \times \frac{dt_1}{m_1} \qquad (2)$$

In practice, the heat transfer of the insulator is subject to "creep," which appears to be due to absorption of water vapour. In addition, the heat capacity of the refractory is sufficiently high to cause the apparatus to have an appreciable response time. Thus it is difficult to maintain a constant temperature difference between the specimen and the enclosure when rapid changes in heating and cooling rates of the specimen occur, for example, during phase changes. These effects have been eliminated by dispensing with the solid thermal insulator, and using instead a vacuum (approximately $10^{-2} - 10^{-3}$ mm of mercury). It has been found(2) that the heat transfer characteristics of such a vacuum are reproducible and appear to be due to "conluction" rather than "convection." A diagram of the pparatus used by Howlett is shown in Fig. 1. Since the ample is held in a stainless steel container positioned by ilica supports, it is now necessary to measure the inverse ates of heating and cooling of the container in addition to he calibration curve using the copper sample. Thus quation (1) would be modified as

$$ {}_1 = \frac{m_2 s_2}{(dt/d\theta)_2 - (dt/d\theta)_3} \times \frac{(dt/d\theta)_1 - (dt/d\theta)_3}{m_1} $$

$$ = \frac{m_2 s_2}{(dt_2 - dt_3)} \times \frac{(dt_1 - dt_3)}{m_1} \qquad (3) $$

vhere $(dt/d\theta)_3$ is the inverse rate of heating or cooling of the ample container.

In the apparatus shown in Fig. 1, for a temperature lifference $\phi \simeq 12°$ C, the rate of heat transfer to the specimen s about 0·001 cal $g^{-1} s^{-1}$ on heating. On cooling $\phi \simeq 8°$ C, nd the corresponding heat transfer from the specimen is bout 0·0005 cal $g^{-1} s^{-1}$. In the original technique used by Smith ϕ had a value of 60° C and it was possible to use a onventional potentiometric controller for controlling the ower input to the furnace. In the present work, however, t is necessary to have a more sensitive controller, because of he lower value of ϕ, and also smoothly varying control.

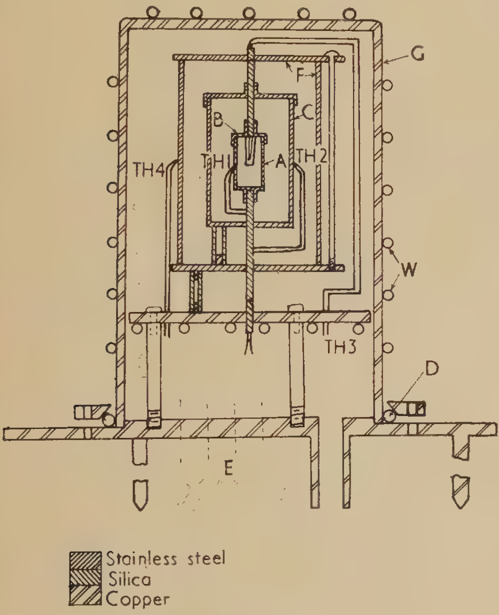

Fig. 1. Sectional view of calorimeter

A, sample holder; *B*, sample holder lid; *C*, enclosure; *D*, O-ring seal; *E*, glass metal seals; *F*, furnace; *G*, water-cooled evacuated chamber; *TH*1, sample container thermocouple; *TH*2, enclosure thermocouple; *TH*3, sample thermocouple; *TH*4, furnace thermocouple; *W*, water cooling coils.

The controller about to be described has been used with he calorimeter shown in Fig. 1. The voltage applied to the urnace winding is obtained from a 2 kW Variac, the comnutator of which is rotated uniformly at a suitable speed by neans of an electric motor *via* a ten-speed reversible gear box. The Variac adjustments necessary to obtain approximately he desired temperature difference ($\phi \simeq 8$ or 12° C) are btained by trial. This temperature difference is further ontrolled to better than 0·03° C by a saturable reactor in eries with the primary winding of the Variac. The control coils of the saturable reactor are the plate load of the single-stage d.c. amplifier shown in Fig. 2.

The method of working of the controller is as follows. The thermocouples *TH* 1 and 2 in Fig. 1 are connected differentially and their output voltage measured using a null potentiometer. A Cambridge 20 Ω galvanometer and a suitable Universal shunt are used to indicate balance. The galvanometer lamp is an 8 W protector lamp and forms an image on the two photocells shown in Fig. 3. These photocells are mounted in an enclosed box which carries a collimator. The interior is given a black matt finish and it has been found that this and the two collimating slits are sufficient to eliminate the effects of stray light in an artificially lighted room.

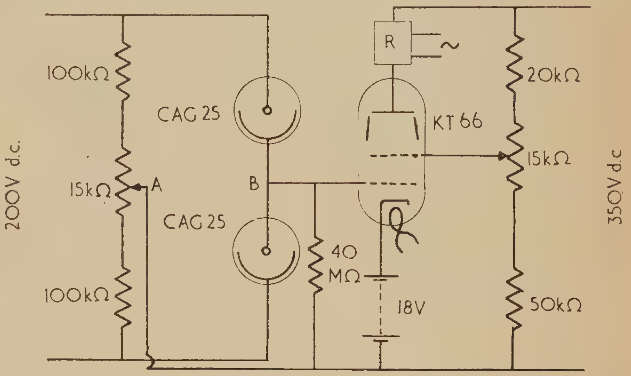

Fig. 2. Circuit diagram of saturable reactor control unit

R, saturable reactor.

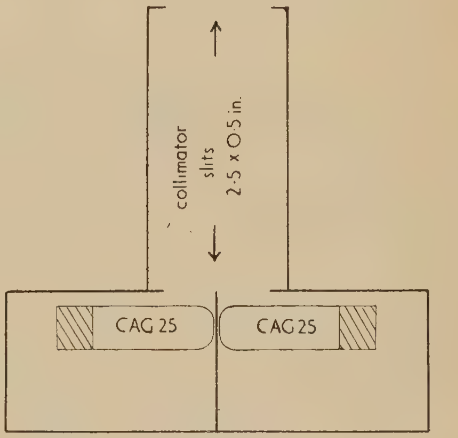

Fig. 3. Plan of photocell unit

In Fig. 2 the two photocells form part of a Wheatstone bridge circuit. When the temperature difference ϕ deviates from the chosen value, the potentiometer goes out of balance and hence the galvanometer image moves from its null position. Thus the amount of light falling on one photocell increases and decreases on the other. The output voltage between *A* and *B* changes and also the control grid voltage of the amplifier valve. This changes the plate current of the valve which alters the reactance of the saturable reactor. By suitably choosing the direction of motion of the galvanometer, the power to the furnace can be raised or lowered smoothly in order to restore the temperature difference ϕ. In principle it is possible to control by means of only the saturable reactor, but this would involve a "long term" steady drift of the temperature difference ϕ in order to effect control. By using the Variac and the saturable reactor together this drift is reduced to less than 0·03° C in 10° C.

The fact that this control apparatus is not "critically damped" must be borne in mind and some experience is necessary in order to establish the experimental conditions and prevent hunting. This is particularly necessary at the beginning and end of a thermal arrest in the sample. Under quiescent conditions (when no thermal changes are occurring in the sample) the apparatus has functioned unattended for several hours.

The problem of critically damping the apparatus is difficult. It arises mainly in the thermal inertia of the furnace, the response time being in the region of one minute, whereas the control apparatus has a response time of several seconds at most. It is not a desirable solution to increase the response time of the control apparatus by placing a capacitor in parallel with the 40 MΩ sensitivity control resistance (see Fig. 2), since, when thermal changes occur in the sample, as short a response time as possible is desirable. This problem can only be solved satisfactorily by lowering the thermal inertia of the furnace. At present a new furnace design is in hand using internally wound strip heating elements.

The present apparatus has only been worked up to 300° C. This maximum is imposed solely by the impedances of th furnace winding and the reactance which together limit th maximum power to the furnace. Therefore it has not bee possible to maintain a temperature difference between th specimen and its enclosure of 12° C at temperatures abov 300° C. Higher specimen temperatures should be obtainabl using a difference less than 12° C.

With the apparatus described above satisfactory specifi heat-temperature curves for a number of magnesium–cad mium and silver–palladium alloys have been obtained. Th smoothness of these curves is about ±0·5% and severa repeat curves for one alloy have shown corresponding specifi heat values within 3% of one another.

ACKNOWLEDGEMENT

The author wishes to thank Prof. G. V. Raynor and Dr B. W. Howlett for permission to publish details of thei calorimeter.

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Simple apparatus for measuring dielectric constants and losses from 10 c/s to 50 kc/s

By J. C. S. Richards, B.Sc., Ph.D., Department of Natural Philosophy, University of Aberdeen

[*Paper received* 21 *July*, 1958]

A simple bridge circuit is used with a battery-operated detector. No coupling transformers or Wagner earth adjustments are required. The dielectric constant is measured by a substitution method, and the losses in terms of the equivalent parallel resistance.

The problem of measuring the dielectric constant of a specimen at any one frequency can usually be reduced to the problem of measuring a small capacitance C_x (5–100 pF say) having a large resistance R_x (usually of the order of megohms) in parallel. At the higher frequencies (greater than 10 kc/s) the resonance method is usually employed, but for a number of reasons this technique is not easy to apply at lower frequencies and some form of bridge network is more appropriate. The difficulties encountered in designing a suitable bridge system arise mainly from (i) the very high impedance of C_x at low frequencies (e.g. 10 pF has an impedance of about 800 MΩ at 20 c/s), and (ii) the fact that, if the behaviour of a specimen over a wide range of frequencies (10 c/s to 50 kc/s say) is to be observed in a reasonably short time, the bridge should be easily balanced and the balance conditions should be as far as possible independent of frequency. It is also desirable that the bridge should be simple to construct and should use readily available components.

These conditions taken together largely preclude the use of a transformer (with a Wagner-earth system) for coupling the bridge to the detector (or the supply). Accordingly, the apparatus shown in Figs. 1 and 2 was evolved. The unknown capacitance C_x is found by direct substitution; the unknown resistance R_x is found in terms of either R_p or R_s. The detector circuit consists of an untuned thermionic valve amplifier with a "magic eye" output stage to indicate when the bridge is balanced. By running this amplifier from batteries and mounting it within the main bridge screening box it is possible to dispense with transformers and at the same time earth one side of the bridge supply. In addition interference from the a.c. mains is made negligible.

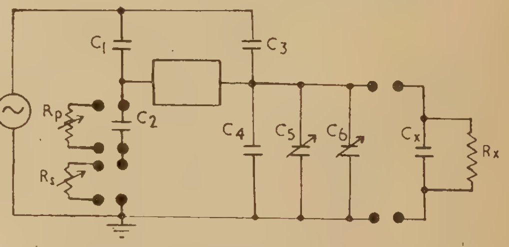

Fig. 1. Circuit diagram of the bridge. C_5 and C_6 are calibrated directly in incremental capacitance. R_s is a decade box (minimum increment 0·1 Ω) employing non-inductive wire-wound resistors. R_p is a decade box (minimum increment 10 Ω) employing high stability carbon resistors of ±1% tolerance. The detector is shown as the box in the centre of the diagram

C_1, C_2 = 0·1 μF mica dielectric
C_3 = 200 pF mica dielectric
C_4 = 100 pF mica dielectrc
C_5 = 30–120 pF
C_6 = 5–20 pF

C_x = unknown

R_p = 0–100 MΩ
R_s = 0–100 kΩ
R_x = unknown

DETAILED DESCRIPTION

The main bridge components, apart from the specimen holder, are mounted in screened compartments on the inside of the detachable front panel (48·3 × 26·7 cm) of a standard ize metal instrument case. The prototype bridge is normally ised for work on solid dielectrics, and for measurements at oom temperature a commercially available holder (dielectric oss test jig, type TJ155A by Marconi Instruments Ltd.) is ised with specimens about 2·5 cm in diameter and 1 to 5 mm hick; this is normally mounted in a screened box with a lid on the outside of the front panel. For other types of specimen, or for work at higher or lower temperatures, suitable holders can be readily devised and, if desired, can be separated rom the remainder of the bridge by several feet of coaxial cable; the value of C_4 is then reduced to compensate for the cable capacitance. It is essential, however, that the insulation of the cable, and of any plugs, sockets or stand-off insulators ssociated with the junction of C_3 and C_4 should have low dielectric losses; polythene, polytetrafluorethylene and Perpex have all been found suitable. For materials having a very high value of dielectric constant, the range of measurement of C_x can be made adequate merely by reducing C_4 and connecting a large value of variable capacitor in parallel with C_1. The capacitors C_1 and C_2 have large values so hat (i) the impedance between their junction and earth is ow and stray capacitances have negligible effect and (ii) the value of R_p required to balance the bridge is not excessively arge. The disadvantage in using so large a capacitance is hat stray inductances may cause spurious effects at the higher frequencies. For this reason, the series resistance box R_s is not used at frequencies appreciably greater than 1 kc/s, and the wiring associated with C_1 and C_2 consists of short hick leads arranged symmetrically with respect to the unction of the capacitors. In particular, when R_s is not in use at high frequencies it must be replaced by a short thick ead, and not merely left in circuit with all the dials set to zero.

The detector complete with batteries is mounted in a small metal box (15 × 12·5 × 12·5 cm approximately) which is fixed to the inside of the front panel by insulating strips. A lid in the detector housing and a slightly larger opening with a hinged lid in the main panel give access to the components and batteries. The on-off and gain switch s actuated *via* an insulated rod passing through holes in both lids; other small holes permit observation of the magic eye. The use of two small dry batteries (11 × 8·5 × 3·5 cm approximately) each providing h.t. and l.t. supplies is necessary to avoid unwanted feedback *via* the power supplies. Since the amplifier takes only a second or two to warm up, and since the zero-gain position of the control switch also disconnects the power supplies, the batteries have a relatively ong life in spite of their small size. Because of the intermittent nature of use, no actual figures of hours of life have been obtained. The minimum detectable signal at the input of the amplifier is about 0·1 mV.

Any suitable oscillator giving more than 10 V r.m.s. output over the frequency range 10 c/s to 50 kc/s may be used with the bridge, provided the output is reasonably sinusoidal (less than 1 or 2% distortion), since the detector is not tuned.

OPERATION

The general method of operating the bridge is obvious and need not be described. Except at the lowest frequencies, R_x is normally found in terms of R_p, since the computation of its value is then trivial. At the lowest frequencies (less than 100 c/s say) the value of R_p required is generally excessively high and it is necessary to use R_s. The computation of R_x is then a little more lengthy.

The accuracy of measurement obviously depends on the constants of the dielectric and the frequency. Unless the dielectric losses are exceptionally large, the error in measuring C_x should be less than ±0·1 pF or ±1%; the dielectric constant will normally have a probable error which is greater than ±1% since it depends on the estimation of fringe-field effects in the specimen holder. The error in estimating R_x varies over a wide range. Provided the product fR_x does not exceed 100, where f is the frequency in kc/s and R_x is measured in megohms, the probable error depends mainly on the components of the bridge and is about ±3%. When fR_x is appreciably greater than 100, the error is mainly determined by the insensitivity of the bridge to small changes in R_p. When fR_x is 500, the total error maybe as large as ±10%, and when fR_x is appreciably greater than 5000, it is usually possible to set a lower limit only to the value of R_x. To improve the accuracy of measurement it would be necessary not only to increase the gain of the detector amplifier, but to consider in detail the effect on the balance conditions of the losses in the bridge components and, at higher frequencies, the effect of the inductance of the wiring. A preliminary study of the problem suggests that it would be difficult to increase the accuracy of the bridge by an order of magnitude while retaining the advantages of a wide frequency range and ease of construction and use.

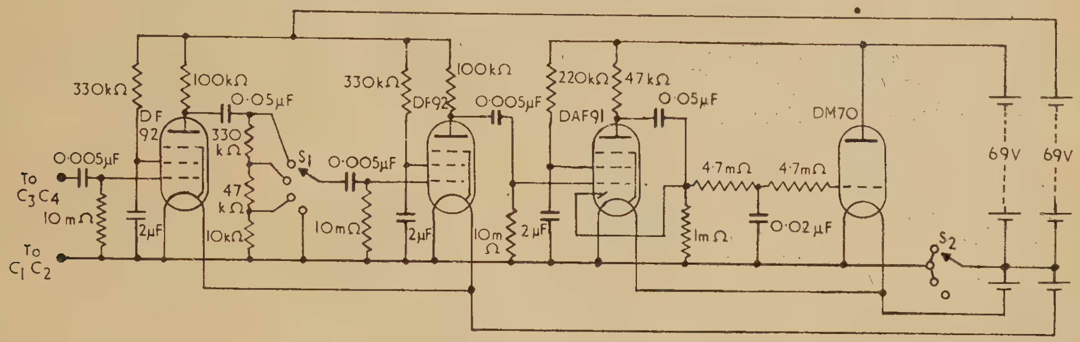

Fig. 2. Circuit diagram of the detector. Switches S_1 and S_2 are ganged. DM70 is a "magic eye" type of tuning indicator

ACKNOWLEDGEMENT

My thanks are due to Dr. D. A. Jones, at whose request this bridge was designed, and to Mr. W. M. Stratton who constructed the prototype.

Radiosonde measurement of vertical electrical field and polar conductivity

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[*Paper first received* 20 *May, and in final form* 10 *September*, 1958]

A field mill and a Gerdian type of conductivity apparatus are described which can replace two standard units on a slightly modified Kew Mk. II radiosonde. They are particularly suitable for an investigation of the electrical properties of the lower atmosphere, including clouds, in non-stormy conditions. Part of each device consists of a current-controlled inductor which varies the frequency of the sonde signal. The limitations and temperature effects are briefly discussed, and the results of a typical sounding given.

Two instruments have been developed to measure, by normal radiosonde techniques, the vertical electrical field and conductivity in the lower atmosphere, particularly in clouds. The conductivity apparatus is similar to that used by Stergis and others,(1) but simplified and modified for use with the British radiosonde. The field is measured by means of a double field mill made symmetrical so that the effects of self charge are nullified. This technique, which is already familiar in aircraft measurements (see, for example, Gunn and others(2)), has been chosen despite its comparative complexity because both radiosonde methods hitherto used, either involving radioactive probes(3) or point discharge currents(4), have the serious disadvantage of polluting the air with ions. Electrical control over the audio-frequency signal of the sonde is obtained by using a type of transductor, and since this is common to both field and conductivity devices it is described first.

THE VICR (VARIABLE INDUCTANCE, CURRENT REGULATED)

In the Kew Mk. II radiosonde, the modulating audio-frequency is altered by mechanically changing the gap of the inductance in a Hartley oscillator, the normal frequency range being from 700 to 1000 c/s.(5) Koenigsfeld,(3) by passing a direct current of 0 to 5 mA through an additional winding on the same inductance, has thereby controlled the frequency electrically. The sensitivity of such a method, however, is not great, and the alternating e.m.f. generated across the control coil is troublesome. Accordingly, a new type of inductance has been devised with enhanced sensitivity, and so balanced that the e.m.f. induced in the control coil is negligible.

The oscillator coil is wound in two halves *A* and *B*, Fig. 1, the number of turns of each depending on the sensitivity required, as shown in Fig. 2. The control coil *C* consists of 30000 turns of 47 s.w.g. enamelled wire, the resistance of which is about 15 kΩ. On top of this is wound a separate coil *D* of 1000 turns of the same wire. The core consists o nine fully interleaved 0·005 in. thick Mumetal lamination (by Magnetic Alloys Ltd., pattern No. 188), but all th U-sections have a small strip about 1 mm wide cleanly cu from each end before they are inserted. It is important tha the laminations should be firmly tied together and th bobbins kept in position with cork wedges, if necessary, t prevent spurious frequency changes.

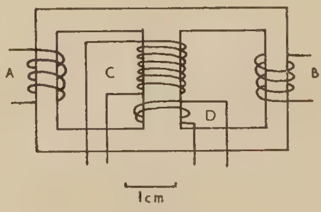

Fig. 1. The variable inductance, current regulated (the VICR)

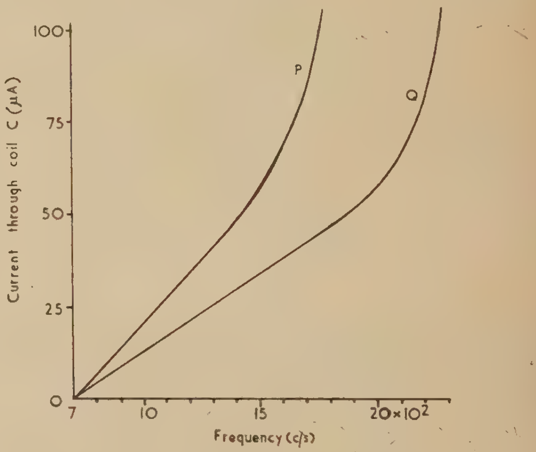

Fig. 2. Sensitivity of the VICR

Curve *P*, with coils *A* and *B* each of 1100 turns, 38 s.w.g.; curve *Q*, with coils *A* and *B* each of 900 turns, 38 s.w.g.

When the coils *A* and *B* are plugged into the sonde in place of the standard element inductance, any current through either of the two other windings raises the oscillator frequency. The d.c. output from the field or conductivity apparatus is passed through *C*, whilst *D* is connected through a 1 kΩ potentiometer to a 1·5 V Drydex DL25 cell. The latter allows the frequency for zero signal through *C* to be set to a pre-determined value. Because any variation of sonde h.t. voltage changes the amplitude of the oscillations, and this affects the sensitivity of the VICR, the amplitude is limited by means of a Mallory cell and germanium crystal, as shown in Figs. 4 and 7. Fig. 2 shows the relationship between current through winding *C* and oscillator frequency for two typical VICR's with different sensitivities, from which it will be seen that the normal range of 700 to 1000 c/s can be obtained for as little as 13 μA. Furthermore, the device is almost linear well beyond 1000 c/s, thus allowing an extended frequency range to be used if necessary.

The hysteresis of the VICR is negligible over the linear portion of its curve, amounting at the most to 1 c/s, but if taken beyond it can be as much as 15 c/s. If the VICR is rotated in the earth's magnetic field, frequency changes of p to 40 c/s may be caused. Consequently, in use it has een found necessary to surround it with a tubular Mumetal hield, 2 mm thick, 6·5 cm long and of 3·5 cm square cross-ection. This has a negligible effect on the performance, but educes spurious signals due to rotation to less than 1 c/s. he temperature coefficient, measured at 800 c/s over the emperature range +15 to −40° C, is found to be +1·2 c/s er degree rise in temperature. However, in practice, as it s padded with foam rubber and enclosed in its Mumetal hield, a thermal lag of several minutes is experienced, as iscussed below. The weight of the VICR in its shield is bout 170 g.

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CONDUCTIVITY MEASUREMENT

Although previous workers have described devices to e used in conjunction with standard radiosondes for the neasurement of atmospheric conductivity, the present pparatus is considered to be more suitable for use in the ower troposphere. It is lighter and more compact than the pparatus used by Stergis(1) and has a quicker response than hose described by Venkiteshwaran and others(6) and oenigsfeld,(3) which give average values of conductivity for arge vertical intervals.

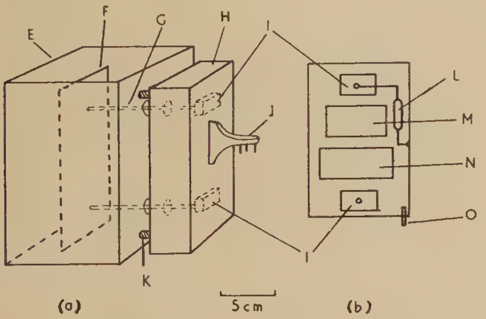


Fig. 3. The conductivity apparatus

The apparatus [Fig. 3(a, b)] is of the Gerdian type, measuring the conductivity of the air flowing between the plates of a condenser when the radiosonde is carried upwards by alloon or descends suspended from a parachute. The uter deflector plates are maintained at plus or minus 15 V vith respect to the central collector plate, depending upon vhich polar conductivity is to be measured. Provided the levice is operating on the correct portion of its voltage-urrent characteristic, the ion current arriving at the collector late is proportional to the conductivity of the air sampled. The ion current is amplified by an electrometer valve circuit, he output of which passes through the control coil of the VICR previously described. Hence, when the conductivity pparatus is in circuit, the audio-frequency transmitted by he sonde is a measure of the conductivity of the air sampled.

For correct operation the condenser should collect only a raction of the atmospheric ions of any given mobility. The ritical mobility for total collection is:

$$k_{crit} = \phi/4\pi CV \text{ (e.s.u.)} \qquad (1)$$

vhere ϕ is the air flow through the condenser in cm³/s, C is he measured capacity between the plates in e.s.u. and V .s.u. is the potential difference between the plates; k_{crit} hould thus be much greater than the maximum mobility of tmospheric small ions in the part of the atmosphere investiated. Values for this apparatus are $C = 16$ pF, $V = 15$ V pproximately, giving $k_{crit} = 20$ cm²/V s at the standard ate of ascent of 5 m/s.

The polar conductivity is

$$\lambda = I/4\pi CV = V_g/4\pi CVR_2 \text{ (e.s.u.)} \qquad (2)$$

where I is the ion current to the collector plate and V_g is the potential difference across the high resistance R_2 (Fig. 4), all in e.s.u. For a fuller description of the operation of Gerdian collectors, reference should be made elsewhere.(7, 8)

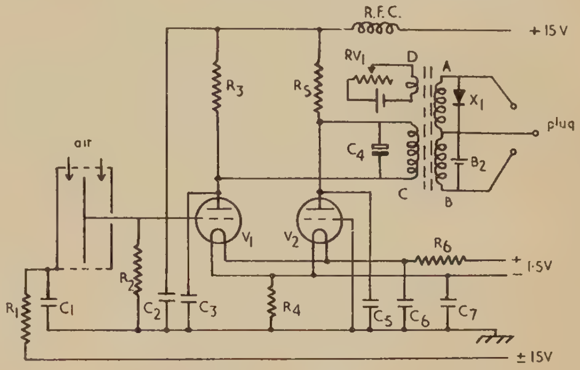


Fig. 4. Circuit diagram of the conductivity apparatus

$R_1 = 1$ kΩ
$R_2 = 10^{11}$ Ω
$R_3 = 22$ kΩ
$R_4 = 15$ kΩ
$R_5 = 22$ kΩ
$R_7 = 10$ Ω

$RV_1 = 5$ kΩ
R.F.C. = 0.2 mH
X_1 = CV448

$C_1, C_2 = 0.04$ μF
$C_3 = 0.001$ μF

$C_4 = 8$ μF
C_5–$C_7 = 0.001$ μF
V_1, V_2 = ME1401
$B_1 = 1.5$ V Drydex T11
$B_2 = 1.3$ V Mallory RM400

The construction of the apparatus is outlined in Fig. 3(a): the deflector plates E, collector plate F, and container for electronic components H, are made from 24 s.w.g. Duralumin. The collector is supported by brass rods G mounted on Distrene insulators I, while the deflectors are secured to the component container by four Perspex insulators K. Plug J is used to attach the instrument to a standard Kew transmitter. Fig. 3(b) shows the interior of the component container, indicating relative positions of the insulators I, VICR in Mumetal shield N, tag board holding the amplifier circuit M, high resistance $R_2(L)$, and the zero-set variable resistance O.

The open ends of the deflectors are covered with half-inch wire mesh to shield the collector from stray capacity effects. If this is omitted the audio-frequency excursions during launching may be large enough to cause appreciable zero-shift due to hysteresis in the VICR. Welwyn 10^{11} Ω silicone-coated resistances are used because of their constancy in humid conditions. The Distrene insulators are machined dry and lightly surfaced with fine emery paper. Measurements of the resistance between collector and earth under normal conditions, due to leakage across the valve-base of the ME1401 and both Distrene insulators, give values greater than 3×10^{13} Ω, which are negligible compared with the 10^{11} Ω grid resistance.

The electronic circuit used is shown in Fig. 4. A change in potential difference between the ends of R_2 from 0 to 0·4 V is sufficient to change the current through the control coil by 13 μA, varying the sonde frequency from 700 to 1000 c/s. This corresponds to a conductivity change from 0 to 10^{-3} e.s.u.; the maximum usable range is 2×10^{-3} e.s.u. The power supply is made up from deaf-aid h.t. and pen cell l.t. dry batteries which operate the device for many hours. Batteries are located with the sonde accumulator in the lagged transmitter case. The balanced type of circuit used gives good stability for small changes in supply voltages, and zero-drift is below 10 c/s per hour on the ground, although somewhat higher in flight.

The method of using the instrument follows from equation (2): V, C and R_2 are measured, and a pre-flight calibration of frequency against V_g is made for each ascent. Hence the received audio-frequencies may be interpreted as conductivity values. The weight of this apparatus, including batteries and VICR, is 550 g.

FIELD MEASUREMENT

The method is based upon the "field mill" principle, and the apparatus has been termed an aeromill. Two similar plates P_1 and P_2 are disposed symmetrically about the sonde, one vertically above the other, and connected to it by equal resistors R_1 and R_2 respectively, and equal capacitors C_1 and C_2, as shown in Fig. 5. Suppose the field directed into the top plate due to the atmospheric field is $+E$, then that into the bottom plate will be $-E$. However, if the sonde itself carries, say, positive charge, and its surface is conducting, this charge will produce a field of $+\varepsilon$, as shown, directed into each plate. Clearly, therefore, the difference between the total field $\varepsilon + E$ into the top plate and that of $\varepsilon - E$ into the bottom one is a measure of the true atmospheric field. If simultaneously both plates are alternately exposed to and shielded from these fields, bound charges proportional to the fields will produce alternating voltages across C_1 and C_2. These voltages, which are also proportional to the total fields, are amplified and their difference determined electronically. It is this difference which, after rectification and smoothing, is applied as a signal to the VICR.

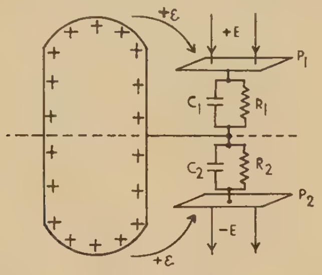
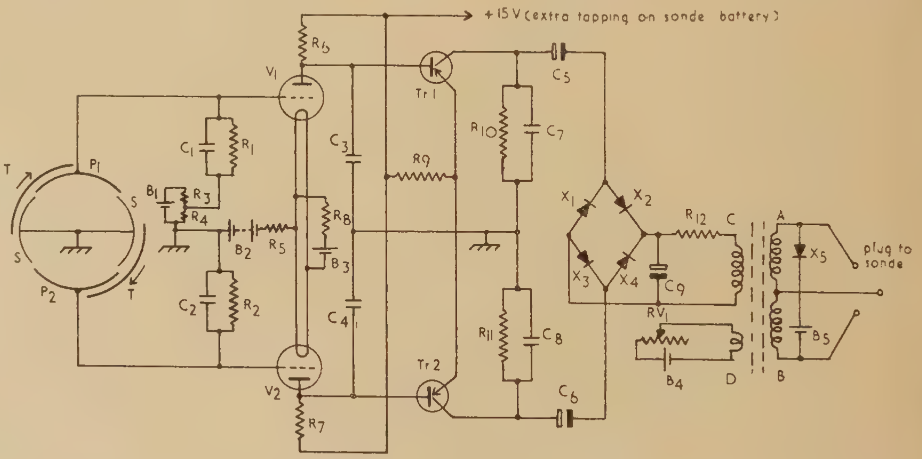


Fig. 5. Principle of the aeromill



R_1, R_2 = $10^{10}\Omega$
R_3 = 2 MΩ
R_4 = 1 MΩ
R_5 = 150kΩ
R_6, R_7 = 100kΩ (see text)
R_8 = 10 Ω
R_9 = 3.3kΩ
R_{10}, R_{11} = 6.8kΩ
R_{12} = 15kΩ

RV_1 = 1 kΩ

X_1 to X_5 = CV 448

C_1, C_2 = 100 pF
C_3, C_4 = 0 04 μF
C_5, C_6 = 20 μF
C_7, C_8 = 0.04 μF
C_9 = 32 μF

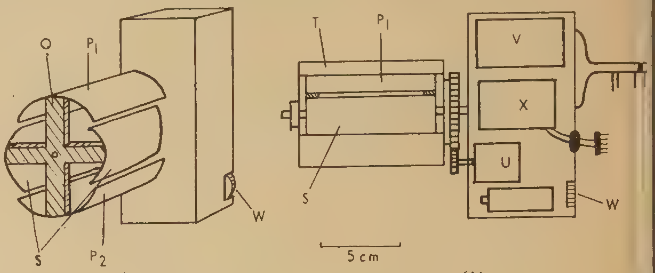
V_1, V_2 = ME1401

Tr_1, Tr_2 = OC71

B_1 = 1.5 V Drydex DL31
B_2 = 15 V Drydex DH521
B_3, B_4 = 1.5 V Drydex DL25
B_5 = 1.3 V Mallory RM400

Fig. 7. Circuit diagram of the aeromill

In practice, the plates are opposite quarters of a circular cylinder, each approximately 9 × 6 cm, Fig. 6(*a*). They are supported on Perspex insulators Q and connected to the body of the sonde through equal resistors R_1 and R_2 and capacitors C_1 and C_2. A cylindrical aluminium cover T [Figs. 6(*b*) and 7], which is rotated about its axis by a small electric motor U, has opposite 90° sections removed as shown so that as it rotates it alternately exposes and shields the plates P_1 and P_2. The plates S are connected to the case of the instrument and shield the interior of the mill from external fields.



(*a*) (*b*)

Fig. 6. The aeromill

(*a*) With cover T removed.
(*b*) With box exposed, showing VICR V, with its zero set potentiometer W, and the position of electronic components X.

Electronic circuit. The input sensitivity of the apparatus is governed by the values of C_1 and C_2 (Fig. 7), and it has been found convenient to have them 100 pF each. The speed of the rotor varies from 6 or 7 rev/s with new batteries, to 2 or 3 rev/s at the end of a flight, and since the rotor covers and uncovers each plate twice per revolution, the frequency of the induced voltage varies between about 15 and 5 c/s; R_1 and R_2 are, therefore, made 10^{10} Ω.

The voltages appearing across the input capacitors are fed into two electrometer triodes connected as a long-tailed pair, so that the alternating difference in anode currents is proportional to the difference in these voltages. Each valve is directly coupled to a transistor in grounded emitter operation, and the signal which appears between their collectors is rectified by a full wave crystal rectifier, smoothed, and applied to winding of the VICR. Resistor R_{12} may be included to reduce the sensitivity and improve rectifier linearity. The anode loads of each valve are individually adjusted to bias each transistor so that the quiescent voltages across R_{10} and R_{11} are about 5 V.

If R_1 is connected between plate and h.t. minus, and not as shown in Fig. 7, the relationship between frequency and field will be as in Fig. 8, curve X. The non-linearity for small fields is due to the rectifying circuit. In order to overcome such non-linearity for the positive fields usually found in the atmosphere, the potential of one plate is arranged to about $\frac{1}{2}$ V above the mean sonde potential by means of R_3, R_4 and battery B_1. This introduces a small constant signal and the response is thereby shifted to Fig. 8, curve *Y*, without seriously affecting the balance of the valves.

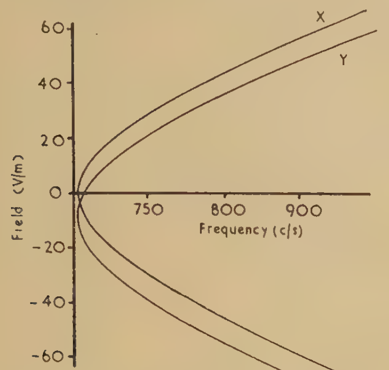


Fig. 8. Calibration of the aeromill

An aluminium box 12 × 7 × 6 cm contains all the components except R_1, R_2, C_1, C_2 and the valves. The latter are grouped round the tube projecting from the box, which supports the insulators and rotor, connexions to them being made through the tube. The rotor is driven by the motor either by means of a rubber band or through a suitable pair of gear wheels. If a rubber band is used it must be coated with a conducting layer of graphite to prevent it from accumulating charge.

With this instrument a VICR with 1100 turn oscillator coils is normally used, and if R_{12} is 5 kΩ the sensitivity is such that the 700 to 1000 c/s frequency change is produced by a field of approximately 200 V/m. The complete weight, including batteries, is 700 g.

Alterations to sonde. The casing is coated with graphite to render it conducting and holes are cut in it to allow the extra battery leads to be brought out. To improve the overall symmetry, a wire, identical to the aerial, is suspended from the bottom of the case and connected to it. The aerial itself is connected to the case through a 1 MΩ resistor so that its mean potential is the same as that of the sonde. With such modifications it was found necessary to reduce the aerial length from 2·2 to 1·7 m in order to retain optimum radio-frequency oscillation. The aeromill is always plugged into the socket opposite the windmill of the Kew radiosonde so that it is shielded by the other two units from any effect due to the rotation of the windmill.

Calibration. Immediately before each flight, a grid voltage against frequency curve is obtained for the conductivity apparatus. The complete sonde is then suspended midway between two plane conductors 3 m square and 1·5 m apart. The effect on the aeromill of charge on the apparatus is first investigated by applying a potential between the sonde and the centre tap of a 1 MΩ resistor connected between the conductors. If this produces a spurious signal, exact symmetry is achieved by slightly bending the tube carrying the insulators upwards or downwards, until the signal disappears. Then the aeromill is calibrated by applying various fields between the conductors.

MEASUREMENTS

Corrections. The only appreciable corrections to be applied are those due to the change in temperature experienced by the apparatus during a flight. They are complicated by thermal lag and therefore two special flights up to about 7 km (−40° C) have been made to evaluate them. During the first, the changes in zero frequencies were observed, whilst during the second the change in aeromill amplifier gain was measured by applying an input signal which remained constant throughout the flight. The zero drift of the conductivity apparatus was found to be approximately −1·5 c/s per minute during an ascent at the normal rate (5 m/s) but only −1·0 c/s per minute on the descent. In the aeromill the zero drift was less than −0·5 c/s per minute throughout the flight, but the change in amplifier gain was considerable because of the change in current gain of the transistors with temperature. During the first ten minutes of the flight the overall sensitivity fell by only about 10%. After this the

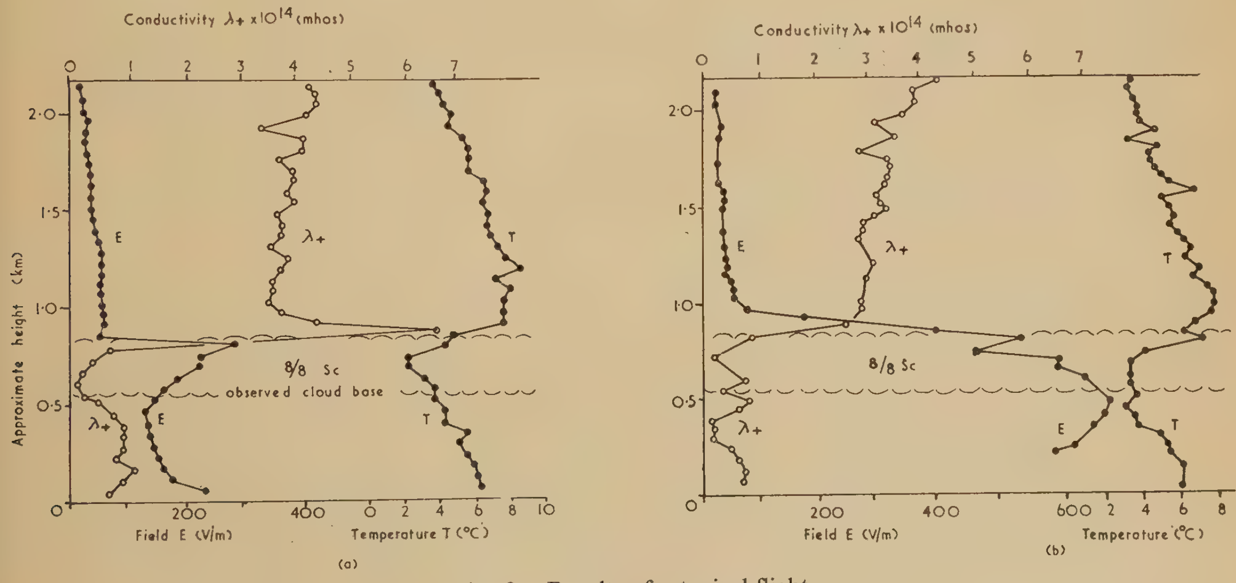


Fig. 9. Results of a typical flight
(*a*) Ascent. (*b*) Descent.

fall became much more rapid, until at the end of twenty minutes the sensitivity was only 50% of its original value. At the beginning of the descent there is again a time lag, of about eight minutes, before the sensitivity begins to increase.

Accuracy. Absolute values of conductivity obtained outside clouds are considered to be ±15% accurate. Inside clouds the conductivity is often low, and in addition a fall in sensitivity of not more than 10% may occur in very humid conditions due to a change in the effective value of R_2. For these reasons values obtained so far in clouds are subject to uncertainties up to +25% or −40%.

Provided that the aeromill has been accurately adjusted so that the effects of self charge are negligible, the error in measurements of the field should not exceed 15% up to about 5 km. Above this height the error increases because of the increasing importance of the temperature correction, which is not itself accurately known.

Fig. 9 shows the results from one flight made at 1530 h G.m.t. at Oxford on 16 January, 1958, through 8/8 stratocumulus cloud to a height of approximately 2 km. Heights have been computed assuming a constant speed of ascent. The only cloud boundary known with certainty is that met first in ascent; all others are probable positions. Above the temperature inversion the agreement of the field and conductivity values between ascent and descent is quite close. Beneath it, however, they are markedly different and this is probably due to the fact that the ascent was made through relatively clean air up-wind of the city, whereas the descent occurred in the area polluted by condensation nuclei, etc., down-wind of it.

CONCLUSIONS

The sensitive device which has been developed for electrically varying the audio-frequency of the Kew Mk. II radiosonde should be readily adaptable to other measuring instruments.

Whilst the aeromill is only suitable for use up to 5 or 6 km the conductivity apparatus should be reliable at much greater heights. The temperature effects on the former could be greatly reduced either at the expense of extra weight, by replacing the transistors with valves, or at the expense of a tenfold reduction in sensitivity, by omitting the transistor stage altogether. On several flights the ascent and descent values are very similar, and confirm the general reliability of both instruments.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Dr. A. W. Brewer for many helpful suggestions and assistance particularly during the development of the VICR. Two of them are indebted to the Admiralty for a maintenance grant during the period of this work.

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Measurement of the temperature of a running thread-line

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[*Paper received* 1 *September*, 1958]

Instruments are described which may be used to measure the temperature of a running textile thread-line. They entail the elimination of the difference in temperature between the thread-line and an independently heated thermocouple.

To measure the temperature of a thread-line it is necessary to make thermal contact, either by conduction or radiation, between it and a temperature sensitive element. So far, it has not been possible to construct and calibrate satisfactorily a device that depends solely on heat transfer by radiation. The instruments to be described depend upon physical contact between the thread-line and a thermocouple which, in one case, projects from the bottom of a groove in a bead of Sintox (by Lodge Plugs Ltd.), and in the other is attached to a small piece of thin nickel foil. It has been found that this contact does not upset the general running of the thread-line in either case.

The first instrument used by the authors is shown in Fig. 1. It is, in fact, a development of an instrument described by Sasaki.* A thermocouple *A* lies in a groove in a Sintox bead *B*. Good thermal contact between the heater *C* and the bead *B* is made by mounting them both on a copper tube *D*. A second thermocouple *E* is used to control the temperature of the system, which is carried in an asbestos holder *G*. The thread-line *F* runs close to, but not touching, the thermocouple *A*. In practice, the measuring head is heated to a steady temperature, and the yarn is then dabbed on to the thermocouple *A*, or *vice versa*, according to the circumstances. It is noted whether or not there is a change in the temperature indicated by the thermocouple *A*. If there is a change, then the temperature of the head is altered until the dabbing procedure produces no change in the temperature of thermocouple *A*. This temperature is then taken to be that of the thread-line. It has been found that sufficient sensitivity is obtained by using a Cambridge workshop potentiometer, together with an external d'Arsonval galvanometer of 10 Ω resistance, and a lamp and scale.

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* Sasaki. *Rev. Sci. Instrum.*, **21**, p. 1 (1950).

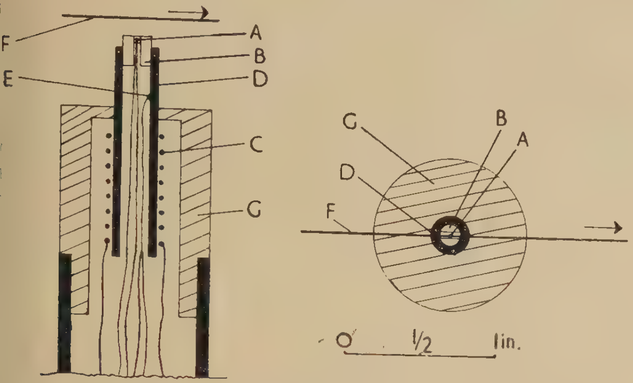

Fig. 1. Instrument for measuring the temperature of a running thread-line

In any particular experiment it is important to check whether there is a source of error in the frictional heating of the thermocouple by the thread-line. This is easily done by mounting the measuring head on a system of levers so that dabbing may be done in a controlled manner by adding weights to a scale pan. In general, it has been found that if the force between instrument and thread-line does not exceed 10 g, then the error due to frictional heating is negligible. The measured temperature is also very nearly independent of the speed of the thread-line. An accuracy of ± 2° C is readily attainable on heavier thread-lines; on the lightest thread-lines it is about ±4° C.

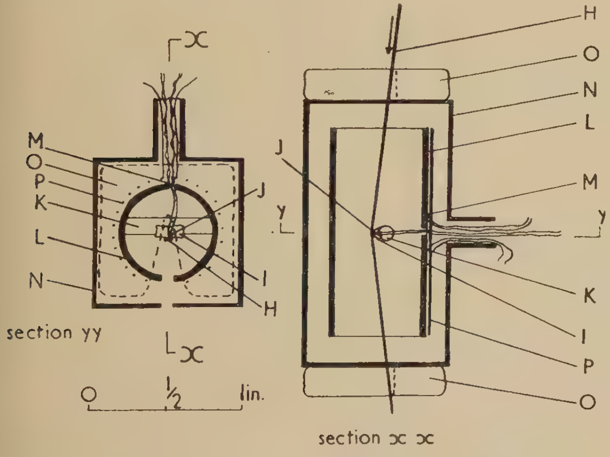

Fig. 2. The second instrument, capable of being left in continuous contact with a thread-line

Since, in some circumstances, it is difficult to carry out the dabbing technique, the authors have attempted to make an instrument which could be left in continuous contact with a thread-line (Fig. 2). The thread-line *H* runs against the shoe *I* of nickel foil. Behind the shoe a thermocouple *J* is soldered. The Sintox pin *K* supports the foil inside the slotted copper tube *L*, the temperature of which can be maintained at a value above room temperature by the heater *P*, and measured by the thermocouple *M*. The brass sheath *N* is also slotted down one side and carries two ceramic guides *OO′* which constrain the thread-line to the centre of the shoe *I*.

The temperature of the thread-line is measured by increasing the temperature of the heater in known steps both with and without the thread-line touching the shoe *I*. The temperature θ of the shoe, and the difference $\Delta\theta$ in temperature between the shoe and the heater is recorded in each case, and the two curves of the kind shown in Fig. 3 obtained. Curve α represents the conditions with the thread-line off the shoe, whilst for curve β the thread-line touches the shoe. When the shoe is at the same temperature as the thread-line, $\Delta\theta$ will be unaltered by the presence or absence of the thread-line on the shoe. Therefore the point *Q* where the curves intersect should give the temperature of the thread-line.

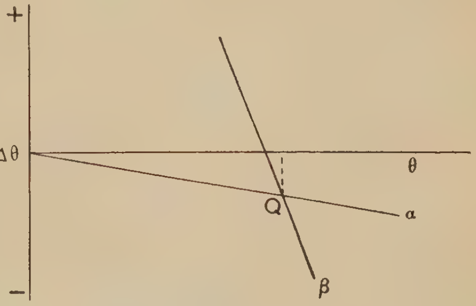

Fig. 3. Method of using the second instrument

Measurements made with both these instruments on yarn taken from an oven under laboratory conditions showed agreement to within 2° C at about 100° C. In use, the second instrument was found to take longer to use than the first, and to be too sensitive to changes in ambient conditions. For example, the slope of the curve α changes with the ambient temperature. The second instrument has been found, however, to give greater accuracy than the first in circumstances where it can be used with a dabbing technique. It was mentioned above that in the first instrument good thermal contact was made between the thermocouple *A* and the heated tube *D*. This made for rapid control of the temperature of the thermocouple *A*, but reduced its sensitivity to contact with a thread-line at a different temperature. In the second instrument the shoe was more nearly insulated, with consequently improved sensitivity.

The first instrument has an advantage in that the measuring thermocouple can be mounted on a probe of small dimensions. It has been used to measure the temperature of filaments of nylon yarn at various stages in their manufacture, and from the accumulated results of many experiments has been shown to be reliable over a range of temperature from about 20 to 200° C.

ACKNOWLEDGEMENT

We wish to thank British Nylon Spinners Ltd. for permission to publish this paper.

Simple, high-sweep-speed, single stroke oscilloscope

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A considerable simplification of a high-sweep-speed single stroke oscilloscope is shown to to result from the application of the accelerating voltage to the tube in the form of a long-tailed pulse. Apart from the power pack the oscilloscope does not incorporate any thermionic valves.

In many instances, notably in the field of research into dielectric breakdown, experiments take the form of the application of single pulses of voltage to a test specimen. Such pulses, which may be of rectangular or double exponential waveform, require to be monitored and sometimes recorded photographically. When the pulse duration is very short (~ 1 μs) the oscillographic equipment tends to become very complicated. An example of a high-sweep-speed oscilloscope designed along conventional lines has recently been published.* When the construction of such an instrument was being considered in detail, it seemed likely that a considerable simplification in the design of the equipment could result from a radical change in the operation of the cathode-ray tube, whereby the accelerating potentials were applied to the tube from a pulse source instead of from a steady d.c. source.

NATURE OF THE NEW SYSTEM

The conventional system is to apply to the accelerating electrodes a steady d.c. voltage of about 10 kV and to prevent the tube from conducting by sufficient grid bias. Just before the impulse wave to be displayed is triggered, a brightening pulse is applied to the grid of the tube and the time-base is triggered. In the model described by Armitage, Gaskin and Phillips, the brightening pulse is obtained from a pulse-forming network consisting of twelve inductors and capacitors triggered by a high-speed thyratron, the same pulse being used to initiate the time-base.

In the new system shown in Fig. 1, a single-stage impulse generator applies a long-tailed impulse wave to the accelerator electrodes just prior to the triggering of the high-voltage impulse to be examined. Zero grid bias is applied to the tube at all times and the time-base voltage is obtained from a capacitance charged through a resistance from the accelerating voltage. Apart from the obvious advantage of simplicity, there would seem to be the following additional advantages:

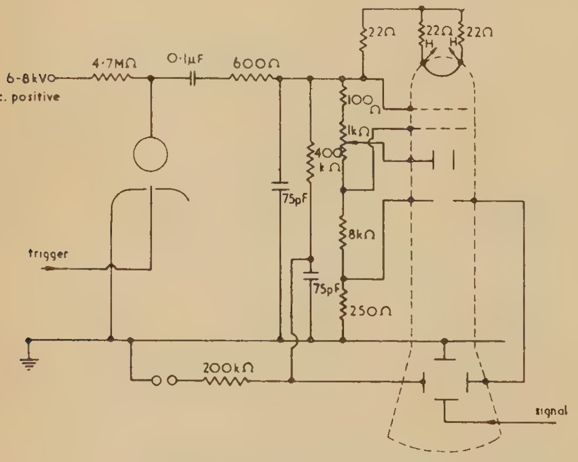

Fig. 1. Circuit diagram of pulsed cathode-ray oscilloscope incorporating a general purpose tube (VCR 112)

(1) the mean power taken from the high-voltage power pack is much reduced, so that cheap and small power packs may be used despite their inherently poor regulation;

(2) very little power is dissipated in the oscilloscope box so that cooling louvres are not necessary. This results in more complete screening;

(3) a pulse voltage of about twice the rated steady d.c. voltage may be applied to the tube, giving an increased brightness, so that up to sweep speeds of 100 cm/μs (single sweep of 1/10 μs) standard tubes may be used.

EXPERIMENTAL WORK

Although the experimental work was limited to that required to develop an instrument to work up to a sweep speed of 100 cm/μs, the following account of that work is believed to be of value and is included for that reason.

The first trials were made with a pulse of up to 8 kV and of about one microsecond duration, applied to a type VCR 112 cathode-ray tube, the pulse being obtained from a length of No. 32 uniradio cable. With this arrangement, the focusing conditions were established. An alternative to the uniradio cable then became necessary because sweep times of up to 10 μs were expected to be required and the necessary length of cable would have been excessive. A chopped-pulse supply was then designed and constructed, the chopping time being obtained from the time-base circuit. Although this circuit proved completely satisfactory, it was abandoned in favour of a simple, unchopped, long-tailed pulse when it was found that the same pulse voltage could be applied to the tube without causing any damage whether the pulse was chopped or not. Under this latter condition, an additional resistor and spark gap were desirable in the time-base circuit to hold the spot off the screen after the sweep until the pulse voltage fell to a low value. The complete circuit of the cathode-ray oscilloscope with impulse source and time-base is shown in Fig. 1. The operation of this latter circuit is as follows. The spark gap is set to break down at a voltage lower than the sparkover voltage of the time-base electrode system in the cathode-ray tube. As the time-base voltage rises, the spot is swept across and off the screen until the spark gap breaks down. From this instant, the potential applied to the time-base plates is a steady fraction of the pulse voltage, the fraction being governed by the values of the series resistors.

The oscilloscope type VCR 112 with which this preliminary work was done has the disadvantage of a very curved screen. It was desirable, therefore, to construct a second model incorporating a photographic tube type 908 BCC. This tube has the connexions to the third anode and to the two sets of eflecting plates brought out at the side of the tube. This rangement yields the additional advantage that the time-ase electrodes are capable of withstanding the full voltage enerated in the time-base circuit, so that the resistor and park gap are not required.

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* Armitage, J. W., Gaskin, G., and Phillips, K. *Electronic Engng.*, **29**, p. 364 (1957).

It was found possible to design the complete oscilloscope rcuit from the tube manufacturer's data, together with that btained from the first model. This design is shown in Fig. 2. weep times of 1, 10 and 100 μs are provided in accordance ith the investigation in hand. A small modification to the me-base circuit enables these sweep times to be reduced by factor of ten. The cathode-ray tube and its associated omponents were fitted into a tube, 14 in. long × 6 in. iameter, fabricated from 1/16 in. thick copper sheet, the ont of the tube being designed to carry a camera.

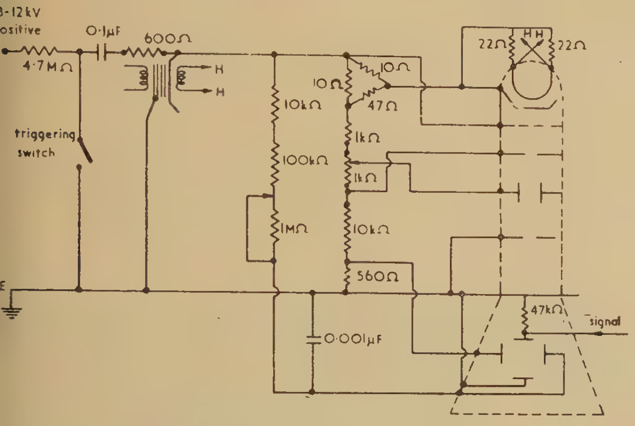

Fig. 2. Circuit diagram of pulsed high-speed oscilloscope incorporating photographic tube (908 BCC)

It was found that the limit of sweep speed appeared to be nfluenced primarily by the stray capacitance to earth of the athode heater winding, which amounted to nearly 50 pF hen wound on to the 50 c/s mains transformer. To over-ome this limitation, a high-frequency heater supply was uilt, consisting of a power oscillator whose tank circuit was a errite-cored transformer matching the valve to the cathode eater.

APPLICATION

A typical impulse generator circuit is shown in Fig. 3 to lustrate one successful application of this new technique. hen the impulse generator capacitors are fully charged and apacitors C_1 and C_2 are charged to the pulse voltage of the .R.O. (10 kV), the mechanical switch *Sw* is closed and two npulses of voltage simultaneously appear across R_1 and R_2. That across R_2 is, in fact, the accelerating pulse for the C.R.O., whereas that across R_1 is the triggering pulse for the impulse generator. After the very short delay associated with the trigatron *T*, the impulse generator fires and the required voltage is applied to the specimen, and a fraction from the potential divider is applied to the Y-plates of the cathode-ray oscilloscope.

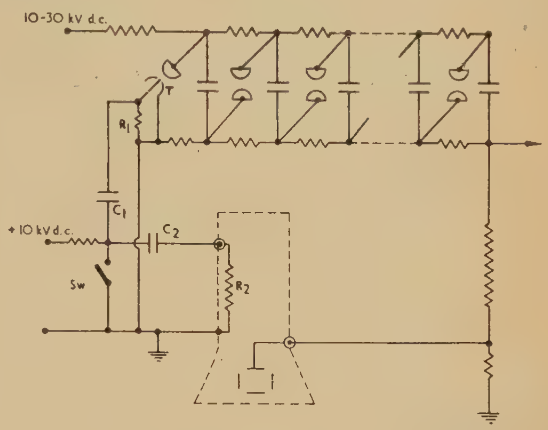

Fig. 3. Application of pulsed cathode-ray oscilloscope to impulse generator circuit

CONCLUSIONS

By the application of the voltage to the accelerating system of a standard cathode-ray tube in the form of a pulse, the performance at high-sweep-speeds is very much improved, due to the increased brightness resulting from the higher accelerating voltage which may be tolerated by the tube. The time-base circuit is reduced to a single capacitance and resistance and the complete circuit has only a few components. Thermionic valves may be excluded from the design.

The linearity of the time-base is at least as good as other circuits, because of the high voltage from which the time-base capacitor is charged. The variation in accelerating voltage during a sweep of 10 μs is less than 1%, which is less than the ripple voltage normally encountered on a steady d.c. high-voltage system. This improvement is even greater at lower sweep times. Similarly, the sensitivity can be predicted to an accuracy at least equal to that of the conventional system.

ACKNOWLEDGEMENTS

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Isotopic analysis of lithium by mass spectrometry

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A mass spectrometer has been built specially for the isotopic analysis of lithium. Conventional solid-source techniques are used, but the tube unit and electronic system have several novel features. Provision is made for pumping down two ion sources at once by having three arms in the mass spectrometer tube instead of the usual two; one arm takes the collector and the other two take ion sources, so that either source arm and the collector form a 60°-sector mass spectrometer. Each source arm is fitted with a vacuum lock to reduce pumping times.

Measurements of the isotope ratio are made semi-automatically once ion beams are obtained. By scanning the magnetic field, each ion beam is brought alternately on to the collector, where it is amplified and "remembered" as a voltage on a capacitor. The amplifier sensitivity is adjusted for one beam until the two voltages are equal, and the isotope ratio is read directly as the ratio of the amplifier sensitivities for the two ion beams.

Fractionation effects in the ion source are described.

The precision of measurement of the isotope ratio is 0·7% at the 95% confidence level, and the absolute accuracy of these measurements is thought to be better than 2%. The instrument is reliable and simple to use, and analyses can be made at the continuous rate of one every twenty minutes.

The mass spectrometer described has been specially designed for the isotopic analysis of lithium, but could possibly be adapted for other elements. A surface ionization source is used; this gives large stable ion beams of ^{6}Li and ^{7}Li from lithium nitrate, but no appreciable background of ions from residual gases in the system, so that relatively high pressures can be tolerated.

To reduce pumping times, a gate valve is fitted between the ion source and the pumping system, and provision is made for using two ion sources by having three arms on the tube instead of the usual two. Since ^{6}Li$^+$ and ^{7}Li$^+$ can be adequately separated even if the resolving power is low, the tube radius can be small and slits in the ion source and collector can be wide to give efficient ion-beam production and collection. In addition, a relatively low accelerating voltage for the ion source and a correspondingly low analyser magnetic field are sufficient, and neither of these has to be particularly stable.

Measurements of the isotope ratio are made by automatic scanning and comparison of the ion beams; in this way the warming-up period of the source is reduced and the measurements are simplified.

THE ION SOURCE

The "triple filament" surface ionization source, shown in Fig. 1, is built in two parts to facilitate cleaning and loading of sample. The inner part supports the stainless steel ion box containing the ionizing tungsten filament and detachable nickel sample supports which are heated by radiation from the centre filament. A constant current supply is used to heat the filament and to keep it at a constant temperature, stability in evaporation rate is achieved by the large heat capacity of the ion box which holds the sample supports. The ion-box assembly operates at 500 V. Large ion beams (2×10^{-10} A) are easily obtained from microgramme quantities of lithium.

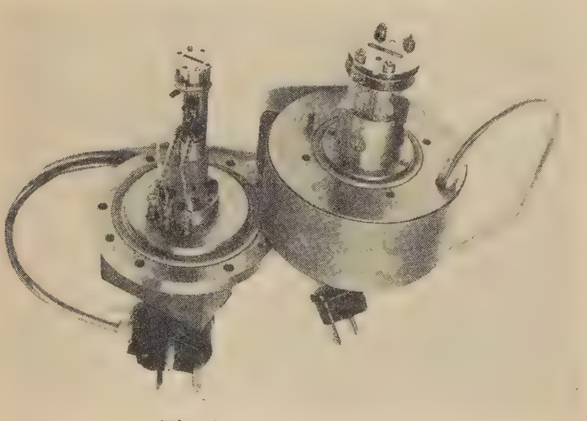

Fig. 1. The ion source

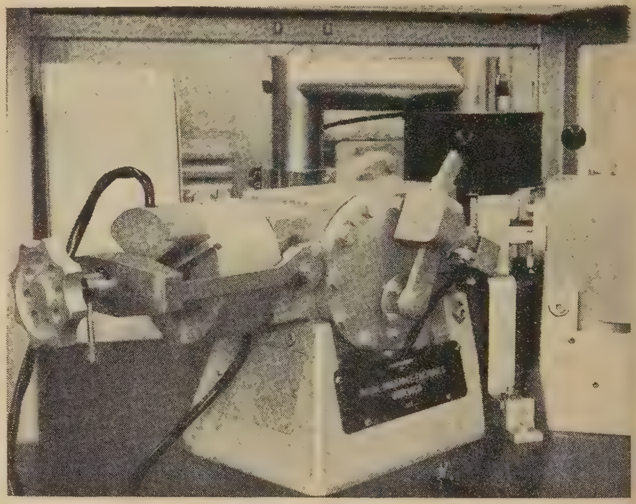

Fig. 2. Ion source mounting and the gate valve

A simple ion optical system is mounted on the other part of the ion source. This consists of a guard ring around the top of the ion box, a focusing slit and an earthed slit. When the parts are fastened together, mechanical rigidity and good alinement are ensured. The quick-release mechanism shown in Fig. 2 holds the source in the mass spectrometer tube.

THE TUBE UNIT

The tube has three arms, as shown in Fig. 3; two take ion sources and the third the collector. Either source arm and the collector form a 60°-sector, 10 cm radius, mass spectrometer. The magnet has triangular pole faces of the correct size for focusing ions from either source on to the collector;

by reversing the magnetic field, either source can be brought into operation.

Stainless steel sheet is welded up to make the analyser tube, which is bolted to brass blocks forming the source arms and to a stainless steel tube for the collector. The brass blocks carry the vacuum locks consisting of a neoprene-seated gate valve operating through a grease-filled Wilson seal. A mercury diffusion pump and liquid nitrogen cold trap pump the tube through wide-diameter line bolted to each of the blocks, and a rotary pump is used for roughing out the source region before opening the gate valve; dry nitrogen is used to let up the source region to atmospheric pressure. After changing a source, the pressure in the tube drops to 2×10^{-5} mm of mercury in five minutes to 5×10^{-6} mm of mercury in fifteen minutes; the limiting pressure is about 10^{-6} mm of mercury.

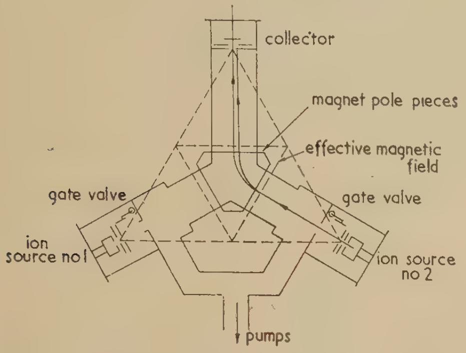

Fig. 3. Schematic diagram of the tube unit

Since the magnet has to be symmetrical for the two source arms, only a limited amount of focusing adjustment is possible and the size of the pole faces is critical. To satisfy the focusing condition it was found that an allowance of 0·8 of the gap width was necessary for the fringing field. The magnet faces are set so that simple reversal of the magnet current gives a field of the correct value to bring ions from either source on to the collector slit. The collector has an entrance slit 0·5 cm wide and another wider slit in front of this to prevent scattered ions from being collected.

ELECTRONIC AND MEASURING SYSTEMS

Ion currents from the collector are amplified by a vibrating-reed amplifier, and the isotope ratio is measured with the aid of the automatic circuits outlined here (see Fig. 4). The two ion beams are brought alternately on to the collector by scanning the magnetic field, and are amplified and "remembered" as voltages on separate capacitors. By synchronized switching it is arranged that the amplifier has a fixed minimum sensitivity for the larger ion beam, and a continuously variable sensitivity for the smaller one; the variable sensitivity is adjusted until the two "remembered" voltages are equal and the ratio of sensitivities then gives the isotope ratio. Equivalence of the two "remembered" voltages is tested by a valve voltmeter which reads the difference voltage. The sensitivity is adjusted by a potentiometer, calibrated in terms of isotope ratio, which alters the feedback ratio of the vibrating-reed amplifier; when this is adjusted to give a zero difference voltage, the isotope ratio can be read off directly. A change in isotope ratio of 0·2% can be easily detected when working with samples in the concentration range 1—99% ^{6}Li.

Although a simple memory system like this works well with increasing ion beams, it fails as soon as they start to decrease because there is no way of discharging the capacitors. Continual discharge at a slow rate is a possibility, but the measured isotope ratio would then depend on the relative time constants of the capacitor circuits. Instead of this, an incremental discharge of about 5% is made, just before each ion beam comes on to the collector, by connecting a small capacitor across the "memory" capacitor which is about to be charged up. Although this incremental discharge produces sharp "kicks" on the difference voltage meter before each steady reading, it does not interfere with efficient operation of the instrument.

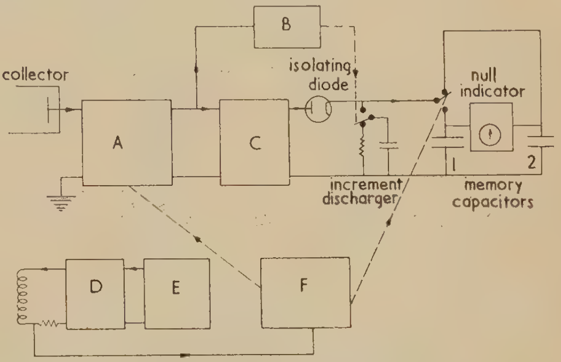

Fig. 4. Block diagram of the beam measuring circuits

A, vibrating-reed amplifier switched between fixed and manually variable gains; *B*, relay amplifier; *C*, d.c. amplifier; *D*, magnet current stabilizer; *E*, reference voltage scanner; *F*, synchronizer.

It is found by experience that the isotope ratio can be measured precisely even if the ion beams change in magnitude by up to 5% during the five-second cycle; this naturally means that measurements can be made very soon after the ion source is switched on (ten minutes is usually sufficient).

Schematic diagrams of all the electronic units have already been published.(1) Provisional patent applications have been made for the tube arrangement,(2) a circuit for the reversal of magnet current(3) and the measuring circuits.(4)

PERFORMANCE

The instrument is extremely reliable and simple to use. The actual measurements are taken during the course of a few minutes, and complete analyses can be made at the rate of one every twenty minutes. The precision and accuracy of measurements are limited by fractionation and mass-discrimination effects in the ion source; these are considered in the following sections.

Fractionation effects in the ion source. Fractionation of the sample of lithium nitrate will occur as it is evaporated, owing to the different molecular masses of $^7LiNO_3$ and $^6LiNO_3$. Measured isotope ratios $R(7/6)$ will be smaller than the true value at first by the factor

$$\sqrt{(^6LiNO_3/^7LiNO_3)} = \sqrt{(68/69)}$$

but owing to the enrichment of the remaining sample in ^{7}Li, the ratio $R(7/6)$ will increase and finally become larger than the true value. By using a large sample and taking measurements before it has time to evaporate appreciably, the value of $R(7/6)$ should be reproducible, and smaller than the true value by $\sqrt{(68/69)}$, i.e. 0·993.

Sample thickness. It is found that the value of $R(7/6)$ depends on the amount of sample used for an analysis. The difference is due not to a change in total sample size, but to a change in the thickness of the layer of solid lithium nitrate; small samples spread over a small area give the same result as large samples spread over a large area. In Table 1, results are given for repeated measurements on samples of natural lithium; in the first column for sample layers of about 40 μg of lithium nitrate per cm^2, and in the second column for sample layers of about 500 μg/cm^2. The difference between mean values is 0·073 ± 0·027. In each case the total sample was large enough to prevent changes in isotope ratio of the kind described in the previous paragraph.

Table 1. *Dependence of measured isotope ratio on sample thickness*

R(7/6) *Thin layer* (40 μg/cm^2)	*R*(7/6) *Thick layer* (500 μg/cm^2)
12·30	12·40
12·32	12·45
12·32	12·37
12·37	12·40
12·31	12·39
12·23	12·26
12·32	12·41
Mean 12·310	Mean 12·383

The reason for this difference may be due to evaporation from a boundary layer or localized hot spots in the thick sample. If imperfect mixing takes place with the sample underneath, fractionation of the evaporating material will be balanced by enrichment of the remaining sample. The isotope ratio of the evaporating material will then be the true isotope ratio. In the thin layer, lithium nitrate fractionates as it evaporates, to give a low value of the isotope ratio in the evaporating material. The measured isotope ratios should then differ by the factor 0·993; actually they differ by 0·994 ± 0·002.

Fractionation of lithium atoms. Occasionally, some of the sample will collect on the centre filament during the warm-up period of the source. When this re-evaporates, it will be dissociated and ionized at the same time to give ^{6}Li$^+$ and ^{7}Li$^+$ directly. Fractionation will reduce the measured isotope ratio *R*(7/6) at first by $\sqrt{(6/7)}$, i.e. 0·926; as the lithium evaporates, *R*(7/6) will increase. In practice, when this effect occurs, *R*(7/6) is found to vary considerably, but the lowest value recorded differs from the true value by 0·927.

Fractionation from the ion box. If the ion box becomes hot enough to evaporate material which is deposited there during measurement, a low value of *R*(7/6) will be caused by the fractionation. Under operating conditions, the temperature of the ion box depends on the length of the tungsten filament being used, as shown in Fig. 5. With a long filament, the power radiated increases as the length increases, and so the ion box temperature rises. When the filament is very short, heat loss from the tungsten ribbon to the filament leads becomes important; the operating current has to be very large to keep the filament at its working temperature of 1600° C and the total power dissipated again increases. The ion box temperature is a minimum at 180° C for a filament length of 6 mm.

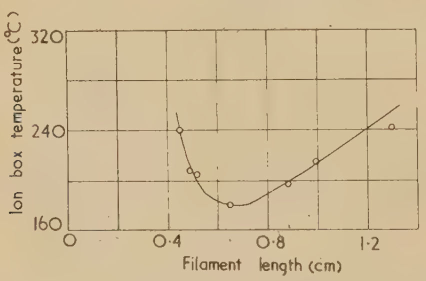

Fig. 5. Variation in ion box temperature with length of ionizing filament

When working with very short or very long filaments, the value of *R*(7/6) is appreciably reduced, as shown in Table 2. The value normally obtained has been established at 12·40 ± 0·02 by a large number of measurements made with filaments of the correct length to keep the ion box at its minimum temperature.

Table 2. *Dependence of measured isotope ratio on filament length*

R(7/6) *Short filaments* (<5 mm)	*R*(7/6) *Long filaments* (>12 mm)
12·18	12·33
12·40	12·37
12·30	12·31
12·31	12·21
12·32	
12·35	
Mean 12·31 ± 0·03	12·30 ± 0·03

PRECISION AND ACCURACY

After making sure that none of the effects just described will give false values for the isotope ratio, repeat measurements on natural lithium nitrate can be made to establish the precision of measurements. The standard deviation for a single measurement is found to be 0·3% of the isotope ratio. This remaining error is probably due to changes in mass discriminations caused by small changes in the ion optics.

Mass discrimination in the ion optics of the ion source will almost certainly cause a systematic error in measured isotope ratio. The only satisfactory way of making absolute measurements, as opposed to relative measurements, is to have standard samples made from ^{6}Li and ^{7}Li, and to use these to determine the mass discriminations. It is hoped that this will be done, but in the meantime the absolute accuracy can only be guessed. From experience in mass spectrometry, it is believed that the total error will not be greater than 2%.

ACKNOWLEDGEMENTS

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The Royal Ordnance Factory, Woolwich, designed the quick-release mechanism for changing ion sources, and constructed the final form of the instrument from the prototype. Their help in supplying half-tone illustrations is also acknowledged.

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Measurement of the falling velocity of particles in opaque fluids

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[*Paper received* 23 *June*, 1958]

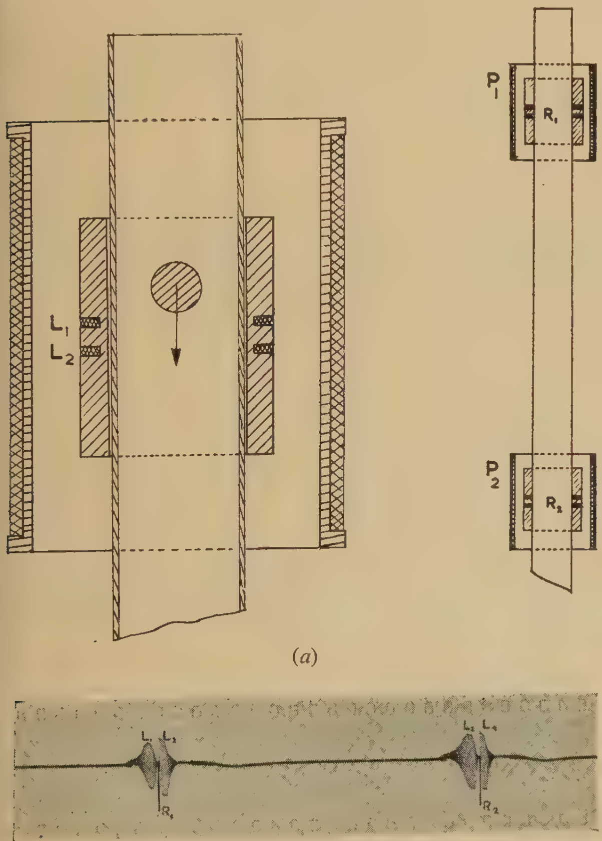
An apparatus is described for the measurement of the falling velocity of small metallic or metal-coated particles through opaque fluids. An electromagnetic method of detecting the particles is employed.

'or a recent research project(1, 2) it was necessary to measure he velocity of fall through opaque fluids of spherical particles pproximately 0·1 cm in diameter. Existing methods(3–9) vere incapable of detecting such small bodies with sufficient recision, and an apparatus based on an electromagnetic nethod of detection was developed.

It consists of a vertical glass tube of 2·5 cm internal iameter containing the opaque fluid and two sets of detection oils placed coaxially with the tube at two positions down its ength (see Fig. 1). The principle of operation is that the econdary coils L_1 and L_2 of the detection system are wound n opposition and their electrical constants are adjusted, so hat when they are suspended inside the energizing primary oil P_1 the currents induced inside them are equal and pposite.

The use of double coils working in opposition to detect hanges in self-inductance caused by the passage of a metallic phere has been reported by other workers.(3, 4, 5, 7) However, heir systems did not include a concentric primary energizing field which greatly reduces the effect of stray electromagnetic fields and gives a big improvement in the sensitivity, stability and accuracy of the system.

As the metallic test sphere on its downward travel approaches L_1 it alters the impedance of the coil, causing a small resultant current to flow in the secondary circuit which, after suitable amplification, is displayed as a voltage signal on a cathode-ray oscilloscope. The out-of-balance signal rises (see Fig.1 *b*) until the test sphere reaches the region between L_1 and L_2 when the induced currents again become equal and opposite resulting in a zero output. This is taken as a reference level R_1, its position being independent of the magnitude of the energizing field and of the gain of the detecting system. The falling velocity of the test sphere can be calculated from the measurement of the time taken for the sphere to travel between two reference levels R_1, R_2 which are separated by a known distance along the tube.



(*a*)

(*b*)

Fig. 1. (*a*) Vertical section through the detection coils. (*b*) Variation of detection signal with the position of a test sphere

CONSTRUCTIONAL DETAILS

The primary and the secondary coils were wound on formers cut from Perspex rod. The coils were made as nearly identical as possible in order to simplify the balancing of the electrical circuit. Their details are given in the table.

Table 1. *Details of detection coils*

Coils	*Dimensions*					
	Length (cm)	*Average diameter (cm)*	*Wire (s.w.g.)*	*No. of turns*	*D.C. resistance (Ω)*	*Self-inductance (mH)*
Primary	6·0	4·50	26	720	11·0	13
Secondary	0·03	3·35	42	100	17·5	0·5

The distance separating the secondary coils which gave the sharpest definition of the reference level R was experimentally found to be 0·75 cm.

The primary coils were energized (see Fig. 2) by a 100 mV signal from a variable-frequency oscillator which was amplified by a variable-gain power amplifier of 8 W maximum power output. The signal induced in the secondary coils passed through a beat-frequency bridge heterodyne detector (sensitive to 1 μV input) and came out as a 1000 c/s signal to be displayed on a cathode-ray oscilloscope. Maximum sensitivity of the instrument was obtained when all the circuit components satisfied the conditions for power matching. In the course of investigations power matching was obtained using a low impedance 1 : 10 step-up matching transformer T, (see Fig. 2) and a signal frequency of approximately 23 000 c/s. The resistive components of the impedances of coils $L_1 - L_2$ and $L_3 - L_4$ were roughly balanced using variable 0–1 MΩ resistances R^1, R^2 connected in parallel with the coils as in Fig. 2. The final balance of the impedances was obtained by adjusting the heights of the primary coils (which were suspended on threaded rods) relative to the secondaries. When correctly adjusted it was possible to detect an out-of-balance voltage of the order of 1 μV corresponding to the signal produced by the passage of a 0·05 cm diameter steel sphere or by a 0·10 cm diameter sphere made of non-magnetic metal. The apparatus was found to remain stable at its maximum sensitivity for indefinite lengths of time provided that all circuit components had reached a thermal equilibrium.

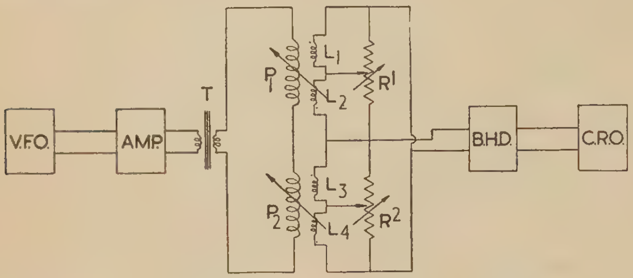


Fig. 2. Circuit diagram of detection apparatus

AMP. = power amplifier.
B.H.D. = bridge heterodyne detector.
C.R.O. = cathode-ray oscilloscope.
V.F.O. = variable-frequency oscillator.
$L_1 - L_4$ = detecting coils
R^1, R^2 = variable resistances, 0–1 MΩ
P_1, P_2 = primary induction coils
T = matching transformer

THE ACCURACY OF THE APPARATUS

The limiting accuracy with which the determination of the falling velocities could be made depended on the accuracy of measuring the distance between the reference levels and the duration of fall of the test spheres.

Provided the distances between the two coils of a pair were adjusted suitably the reference level was precise to ±0·01 cm. The maximum error in determining the fall distance could therefore be reduced to less than 0·1% by having the reference levels 20 cm or more apart.

The timing of the fall was carried out with a stop-watch for slowly falling spheres and photographically for faster ones. In the latter case a double-beam cathode-ray oscilloscope was needed. The second beam of the oscilloscope was connected to a reference time-base and photographed simultaneously with the detection signal using a variable speed oscillograph camera (see Fig. 3). In general the a.c. mains supply was used as the reference time-base, the exact frequency being obtained at any time by enquiring at the local power station. It was found to vary by less than 0·1 c/s in the course of one to two hours, constituting a maximum error of ±0·2%.

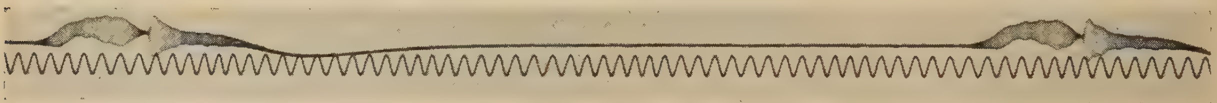


Fig. 3. Photographic record of the fall of a 0·238 cm diameter steel sphere. Film speed $\doteq$ 5 in./s

The random error in reading the time of fall from the fil strip varied between 0·1 and 0·4%, depending on the spher and fluid under investigation and the film speed used.

Thus the limiting accuracy in the determination of th falling velocity using the above arrangements is considere to be ±0·3%. It could be improved by the use of a bett frequency standard and longer distances of fall.

As a test of the accuracy of the detection apparatus th speed of fall of a steel sphere 0·119 cm in diameter through a aqueous glycerol solution, of viscosity 227 cp and densi 1·187 g/ml., was measured both electromagnetically an visually. The average results for ten observations were:

velocity by electromagnetic method = 2·038 ± 0·006 cm
velocity by visual method = 2·046 ± 0·025 cm
velocity calculated from Stokes' law = 2·036 cm/s

With the apparatus consistent results were obtained fo metallic and metal-coated spheres of diameters from 0·07 to 2·00 cm falling with velocities from 0·1 to 200 cm through pure fluids and aqueous suspensions. Wat jacketing of the fall tube was, of course, necessary in order t maintain a constant temperature in the fluid under invest gation and this side of the work is described elsewhere.(1)

ACKNOWLEDGEMENTS

One of the authors (V.F.) wishes to thank the Nation Coal Board for the financial support in carrying out the wor

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Special type of grating, possessing the properties of a neutral filter for use in homochromatic photometry

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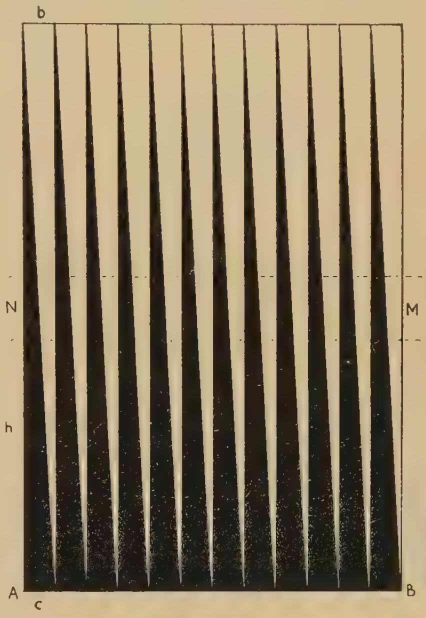
[*Paper received* 28 *July*, 1958]

A transmission grating having wedge-shaped opaque and transparent elements is described. It is shown that it has the properties of a truly neutral filter and can be used in homochromatic photometry in the place of a rotating sector disk which is difficult to operate. This new optical device may be particularly helpful when it is desired to change the intensity of a beam of light by very small amounts. It may also find useful application in absorption spectroscopy.

Homochromatic photometry requires calibration of the response of the emulsion of the photographic plate to light of varying intensity. An obvious method of calibrating the emulsion would be to expose various areas on it to a spectrum of constant intensity, for equal times of exposure, through a series of neutral filters that transmitted equal fractions of the light of each wave-length to the plate. Unfortunately, truly neutral filters are not available and filters called neutral show variations in transmission with wave-length that may amount to 10% or more in the visible region alone. In recent years, however, it has been demonstrated that the rotating sector disk, if operated under carefully controlled conditions, can be made the equivalent of a neutral filter and this is the most common method of varying light intensity. Obviously the sector disk is difficult to operate and Webb* has shown that for each intensity, emulsion and wave-length, a critical frequency of flash exists above which alone it is safe to use intermittent exposures as equivalent to continuous, which means that the sector has to be run at a speed greater than 1200 rev/min. Hence the need for a simple optical device easy to operate which will function as a truly neutral filter.

The special type of transmission grating shown in the figure, having wedge-shaped opaque (width c) and transparent elements (width b), appears to have the properties of a neutral filter. It is clear from the figure that the width of the grating element $(b + c)$ is constant and that the mean width b of the transparent element at a wide horizontal slit MN placed behind the grating is proportional to the height h of the slit above the bottom edge AB of the grating. When a beam of parallel rays of composite light originating from the vertical slit of a collimator passes through the horizontal slit MN centrally placed with respect to the beam and gets diffracted by the grating, the zero order diffracted image of the collimator slit formed at the focus of a telescope objective will have an intensity I proportional to N^2b^2, where N is the total number of grating elements. Since b is proportional to h, we may write $I = KN^2 h^2$ where K is a constant. Keeping the position of the slit MN fixed and raising or lowering the grating, the intensity I may be altered by any desired known amount, using always the same section of the incident beam. The intensity corresponding to each wave-length of the composite light in the zero order image changes in the same proportion. If this image is made to fall on the slit of the spectrograph, the required calibration of the response of the emulsion to light of different intensity can be performed with ease.

A grating of this type having forty-four transparent elements/cm was constructed by a photographic process. On a large sheet of drawing paper a sketch resembling the grating was drawn and alternate wedges were painted black with Indian ink. A miniature photograph of the sketch of the required size was taken with a good camera, and the developed negative suitably cut and mounted served as the grating. To test the properties of the grating, the intensity of the zero order diffracted image was measured using a photomultiplier galvanometer unit, in which the galvanometer deflexion θ was found to be directly proportional to the intensity I of the light that fell on the photomultiplier. Displacing the grating vertically upwards relative to the fixed slit MN, the height h was varied by equal amounts and the deflexion θ was noted in each case. The plot of θ against h^2 gave a true straight line passing through the origin.



Grating with wedge-shaped elements

Transmission gratings of this type may be used whenever a beam of light has to be compared with itself after being absorbed, scattered or attenuated by other means. Particularly when it is desired to change the intensity of a beam of light by very small amounts, this optical device may be helpful. It may find useful application in absorption spectroscopy.

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* Webb, J. H. *J. Opt. Soc. Amer.*, **23**, pp. 157, 316 (1933).

Surface ionization source for mass spectrometry

By R. D. Craig, B.Sc., Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester 17

[*Paper received* 8 *August*, 1958]

The source described is based on the principle of replacement of the usual "source slit" by a demagnified image of the ionizing filament. Using a 0·030 in. wide filament and 0·040 in. wide slits an effective source width of 0·003 in. has been obtained.

The approach adopted[(1)] in previous designs of ion source for the surface ionization of solids has been to modify a standard electron bombardment source of the Nier type, simply by removing the electron gun and substituting a triple filament assembly in the ionization chamber. However, this results in a rather complex design in which, for maximum sensitivity, the geometrical alinement of the filament and electrodes can be critical. This has disadvantages since the filament has to be changed with each sample and in some designs[(2)] it is necessary to separate the source in two parts, one of which is retracted through a vacuum lock.

The underlying principle of the new design is the replacement of the usual mass spectrometer "source slit" by a demagnified image of the filament itself in a source where the actual slits are all wide. This is done effectively by the immersion lens, comprising electrodes 1, 2 and 3 in Fig. 1, which forms a filament image within its own field in about region *A*. Other details of the design are the addition of a collimating slit, electrode 4, to restrict the final beam divergence to ±½° and the splitting of focus electrode 2 into two half plates to permit electrical compensation for any slight mechanical asymmetry.

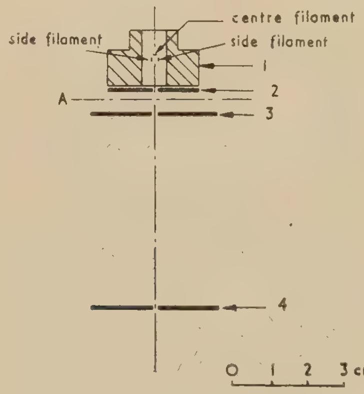

Fig. 1. Surface ionization type ion source

Electrode	*Potential*	*Slit width (mm)*
centre filament	+6000 V	
side filament	+6000 V to +5995 V	
No. 1	+6000 V	6·4
No. 2	+6000 V to +4500 V	1·0
No. 3	earth	1·0
No. 4	earth	1·0

The width of the filament image can be varied from 0·3 to 0·1 times the geometrical width of the filament by varying the mean potential of focus electrodes 2 over the range 80–100% of the full h.t. voltage. As would be expected, from analogy with cathode-ray tube gun design, this variation in image size is accompanied by an approximately inversely proportional change in divergence angle of the ions from the image. Thus, the source efficiency is greater with a broad image than with a narrow one, since for the former case there will be a smaller loss of ions at collimating slit 4.

Advantages of the new design of ion source are:

(1) Simplicity, both from the point of view of engineering and ion optics;

(2) Lack of critical position of filament;

(3) Use of wide slits throughout permitting high sensitivity with high resolution.

Moreover, the troublesome hydrocarbon ions originating on the low temperature side filaments, mentioned by Inghram,[(1)] can be suppressed simply by biasing these filaments a few volts negative. No tertiary ions[(3)] were observed, probably because there is negligible primary ion bombardment of slits 2 and 3.

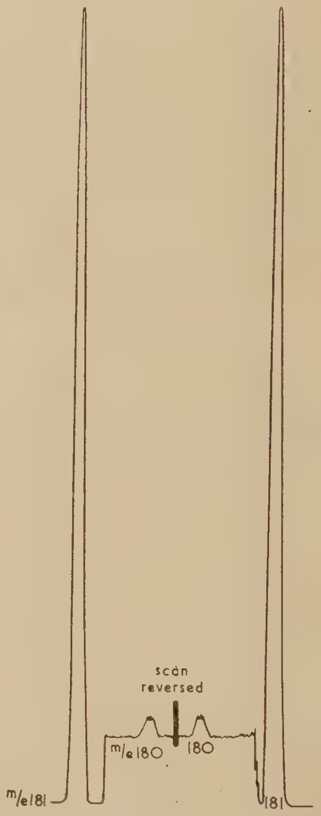

Fig. 2. Tantalum spectrum taken using a 0·030 in. wide filament

(Collector slit 0·010 in.; 180-beam ~ $3 \cdot 10^{-17}$ A)
Sensitivity: ×1 for m/e 180
×1/200 for m/e 181

The source has been in routine operation for several years on a 12 in. single focusing sector type mass spectrometer (type M.S.5 by Metropolitan-Vickers Electrical Co. Ltd.) and the spectrum shown in Fig. 2 is typical of the performance obtained.[(4)] This is an automatic recording of the tantalum isotopes and was taken using a 0·030 in. wide filament. The solution shown corresponds to a beam width at the ollector of 0·006 in.

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Low background gas flow-counter*

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[*Paper received* 25 *August*, 1958]

A low background flow-counter of comparatively simple construction, operating in the Geiger region, is described. The sample counter is shielded by mercury and surrounded by an anti-coincidence ring of eighteen overlapping counters, a top counter, and lead and mercury shields. The counting efficiency with 1 in. diameter steel planchets is 62% for low energy β particles such as ^{14}C; the background is 1·040 ± 0·005 counts/min; and the limit of sensitivity is 0·025 counts/min.

certain biological experiments it becomes necessary to ount samples with only a few disintegrations of low energy -particles per minute. Commercially available 2 π flow-ounters have a background of around 18–20 counts/min. wing to the fluctuation of the background it is impossible count a few additional counts with the desired accuracy. n appreciable reduction of the background without loss of ounter efficiency is therefore the only way to count solid mples of very low activities. Internal gas counting is bout twice as efficient, but the inconvenience of this method uring routine work prompted the authors to build a counter r solid samples, although an improved and comparatively mple gas counter has been described by Sverak.(1)

The possibilities of reducing the background rate of end-indow counters was discussed by Grummit and others.(2) hese investigators used an upright version of the well-known orizontal design of Anderson and others,(3) and added an nti-coincidence counter above the sample counter. A ackground of 0·9 counts/min could be obtained with ertain arrangements. However, no details of the construc-on of the counter and its performance were given. Recently, oftky and Nather(4) have announced a commercially vailable low-background end-window counter (Tracerlog(5)) ith a background of less than 1 count/min. The efficiency f such end-window counters is about 50–70% of that of the π flow counter described below.

COUNTER CONSTRUCTION

The upright design of Grummit and others(2) is used in e present flow-counter. The sample counter (see Fig. 1, C) (hard copper tubing $1\frac{1}{4}$ in. outer diameter and 3 in. igh) is permanently mounted with a flange on a cast iron ase-plate *BP* and sealed with type A2 cement (by Armstrong roducts Co., U.S.A.). It is surrounded by a hollow, cylin-rical iron container (3 in. outer diameter, $1\frac{5}{32}$ in. inner dia-eter, and 7 in. high). The 1 in. space between the walls is lled with mercury for shielding. The anti-coincidence shield onsists of a double ring of eighteen overlapping counters hich surround the mercury side shield. A pot-shaped anti-oincidence counter consisting of a ring *RAC* and centre *AC* counter, and a small mercury shield, are placed above the sample counter. Lead rings 2 in. wide ($11\frac{1}{8}$ in. outer diameter and $7\frac{1}{8}$ in. inner diameter) are positioned around the anti-coincidence counter ring, and a 1 in. thick mercury shield and a lead disk 2 in. thick ($11\frac{1}{8}$ in. outer diameter) are placed over the top. About 30 kg mercury and 140 kg

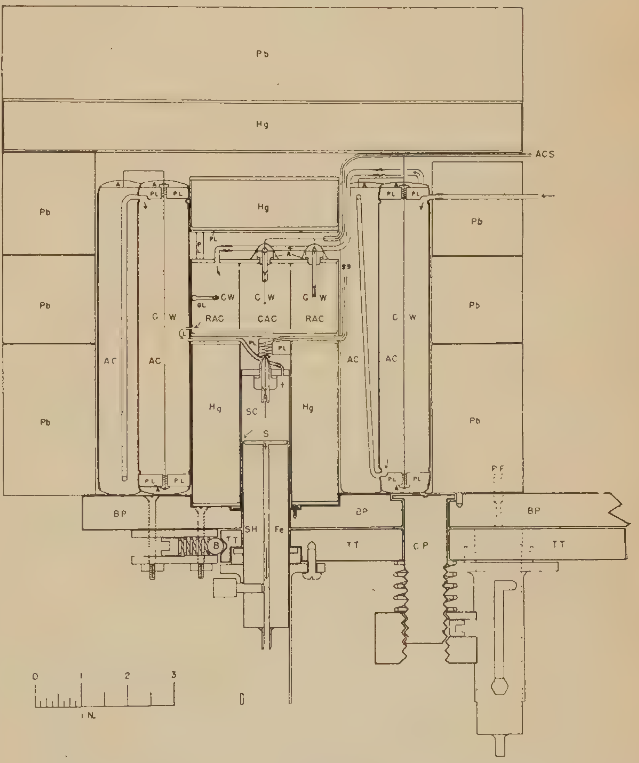

Fig. 1. Diagram of low background counter, vertical section

A, Armstrong cement; *AC*, side anti-coincidence counters; *ACS*, coaxial cable carrying the *AC* signal; *B*, ball; *BP*, base-plate; *CAC*, top anti-coincidence centre counter; *CP*, centre pivot; *CW*, anode centre wires; *Fe*, iron; *GL*, glass arm support for *CW*; *Hg*, mercury shields; *L*, loop in tubing; *Pb*, lead shields; *PF*, pre-flush gas inlet; *PL*, Plexiglass; *RAC*, top anti-coincidence ring counter; *S*, sample planchet; *SC*, sample counter; *SH*, sample holder; *SS*, coaxial cable carrying the sample signal; and *TT*, turntable.

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* Contribution No. 415, Division of Forest Biology, Science ervice, Department of Agriculture, Ottawa, Canada.

of lead (plumbing grade) are necessary for the shielding described above.

The iron base-plate *BP* (13 × 13 in.) mentioned above stands on four legs ($\frac{3}{4}$ in. pipes 5 in. long, Figs. 1–3) and carries on its underside the turntable *TT* (iron disk $\frac{5}{8}$ in. thick). The latter turns on a centre pivot *CP* and its highly polished, greased upper surface is pressed against the polished under surface of the base-plate by a heavy spring. On the under side of the turntable towards the periphery are mounted three sleeves with a flange (steel tubing 3 in. long including the flange) carrying the iron sample holders *SH* (1 in. diameter, 4 in high), which have a small shoulder on top to hold the planchet and are drilled through the centre. Above the flange of the sleeve are a Teflon gasket and a rubber ring gasket (greased with high vacuum silicone) seated into the turntable; these provide a satisfactory seal for the vertical movement of the sample holders. The sample holders in the turntable match exactly with holes in the base-plate underbeath the counter and the loading position. The turntable is positioned by a ball *B* and spring arrangement mounted against its circumference. Most of the details of the construction can be seen from the diagrams (Figs. 1–3). However, a few additional words may be helpful. Several types of anti-coincidence counters, including an annular fin counter, were tried but the following design was finally found to be most satisfactory and easy to build.

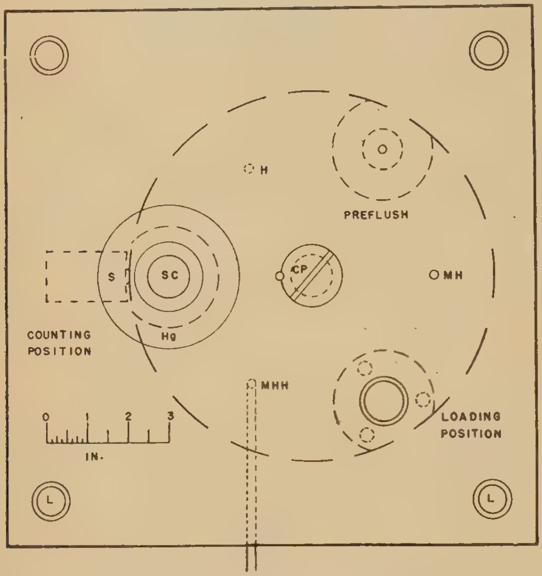

Fig. 2. Diagram of low background counter, horizontal section of lower part showing square base-plate and turntable

CP, centre pivot; *H*, hole in turntable; *Hg*, mercury side shield; *L*, legs; *MH*, matching holes in turntable and base-plate; *MHH*, matching holes in turntable and base-plate (horizontal); *S*, spring arrangement; *SC*, sample counter.

The eighteen anti-coincidence counters (see Figs. 1 and 4) are made of hard copper tubing ($1\frac{1}{8}$ in. outer diameter, $6\frac{1}{2}$ in. long). First, shoulders are pressed into each counter, $\frac{3}{8}$ in. from each end, by using a very blunt tube-cutter wheel. Then $\frac{1}{8}$ in. holes are carefully drilled at the outside margin of the shoulder. Into these holes are silver-soldered the copper tubes ($\frac{1}{8}$ in. outer diameter) which connect all eighteen counters in series. The inside of all counters is very carefully cleaned and highly polished. A Plexiglass disk *PL*, $\frac{1}{4}$ in. thick with a tapped centre hole, is pressed into each end of each counter until it rests on the shoulder and in such position that a notch at its inside face matches with the g inlet hole. Both ends of the counter are "capped" by pressi a conical-shaped (15°) die over them in a vice. Brass machi screws (round head 8–32-$\frac{3}{16}$ in.) are provided with a cent hole and screwed tightly into the centre holes of the Plexigla disks. The centre wire (0·003 in. chromel) and a piece hook-up wire are inserted through the holes and quick soft-soldered under tension to the previously tinned scre heads. Each counter end is now carefully sealed wi Armstrong cement *A*.

The top anti-coincidence counter (*RAC* + *CAC*) is a p made from a $1\frac{1}{2}$ in. long piece of copper pipe ($3\frac{1}{8}$ in. out diameter) with a copper bottom silver-soldered to it. Th top cover is press-fitted and held in place with three clamp (it might be threaded and screwed in). A copper tube ($1\frac{1}{4}$ i outer diameter) with some holes at its upper end is silve soldered in the centre on the underside of the cover. Bot screws carrying the centre and loop wires (0·003 in. chrome are screwed tightly using a Teflon gasket and are sealed wit Armstrong cement. The loop wire is held in the eyes c three glass arms which are attached to a glass ring at th periphery of the pot. The ends of the loop are twisted an fused into a vertical glass tube, which is attached at its lowe end to the glass ring while its upper end is pushed throug the screw. Armstrong cement is applied to seal the scre assembly.

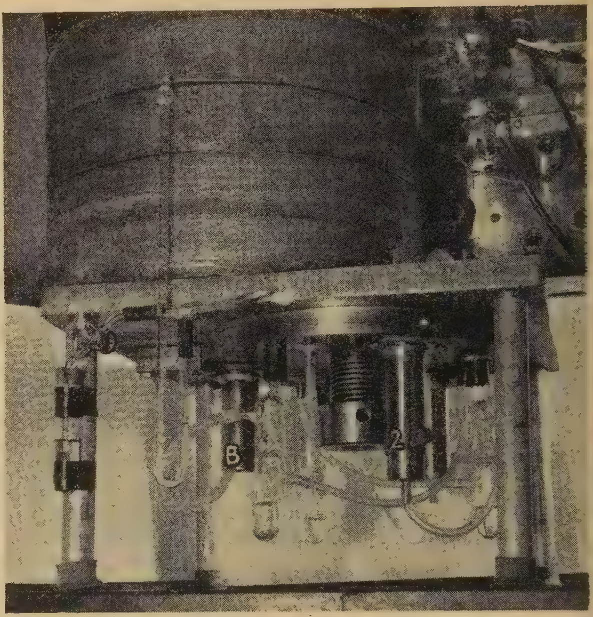

Fig. 3. Photograph of lower part of low background counter showing from top down, lead shield, base-plate, turntable, spring-loaded centre pivot, three sleeves of sample holders, four bubble traps, manometer and anti-coincidence counter chassis on upper right. The sample holder of sleeve *B* underneath the counting position is pushed up into sensitive volume. Sample holders of sleeve 2 underneath the loading position and under pre-flush position are lowered

The centre wire of the sample counter is made of platinur wire (0·005 in.) which terminates in a small bead at th lower end and is soft-soldered to the heavier platinum lead out wire, which is fused in a Pyrex glass tube terminating i ead. Armstrong cement is used for sealing. The whole ntre wire assembly can be removed and replaced from derneath the sample counter with a nut drive by removing e sample holder and sleeve.

The Geiger gas, coming from the reducing valve of the ttle in polyethylene tubing (type PE380 by Clay-Adams, c., U.S.A.), passes first through a bubble trap, a three-way pcock (convenient for changing bottles) and enters at the

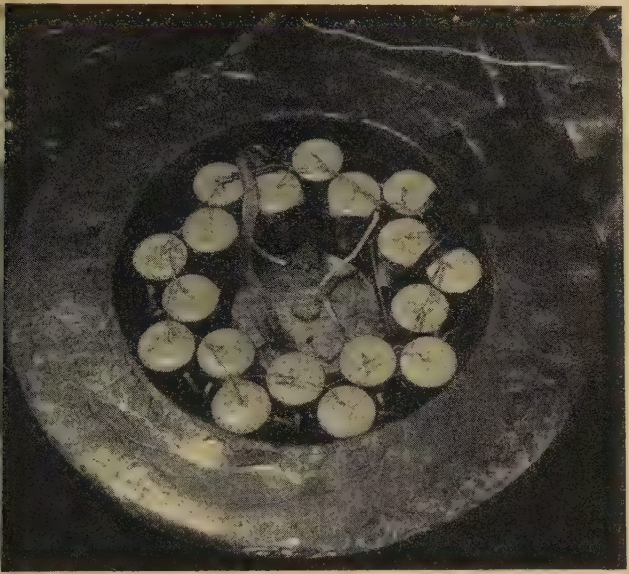

Fig. 4. Photograph of top part of the low background counter after removal of top lead and large and small mercury top shield, showing eighteen tube-shaped side and pot-shaped top anti-coincidence counters, with electrical and gas connexions. Coaxial cables carrying the anti-coincidence and sample signal are seen at upper right

p of the anti-coincidence (*AC*) counter No. 1 (see Figs. 1 nd 4) and leaves at the bottom. It passes in sequence through ach of the *AC* counters, entering at the top and leaving at the ottom of each. It leaves from the bottom of *AC* counter. o. 18 through a vertical copper tube *via* a plastic connecting ibe into the top of the top *AC* counter (*RAC*). From there leaves through a side arm (injection needle No. 18) at the ottom *via* a loop of polyethylene 160 tubing to enter through similar injection needle at the top of the sample counter. The loop is positioned in the space between two *AC* counters. From the sample counter the gas follows the course shown in Fig. 5. The bubble trap connected to the loading position is not in the flow circuit. This flow system with four bubble traps could be replaced by proper connecting channels in the base-plate and turntable and two bubble traps. It is important that all metal connectors are ridged, very smooth and only slightly bigger than the inside diameter of the polyethylene tubing. This kind of tubing, and Teflon even more so, cracks and splits very readily. The ends of the tubing should be carefully softened by hot air or a small flame before pushing over the greased connectors. The open-end manometer is made by fusing a 0·2 ml. pipette (scale length about $6\frac{3}{4}$ in.) with a glass tube ($\frac{3}{8}$ in. inner diameter) into a U-shape (Fig. 3). The first and last bubble trap should produce large bubbles and be calibrated in order to be able to check for gas leaks. This is also the main purpose for the manometer. All bubble traps and the manometer are filled with silicone diffusion pump oil (type D702 by Dow Corning Co., U.S.A.).

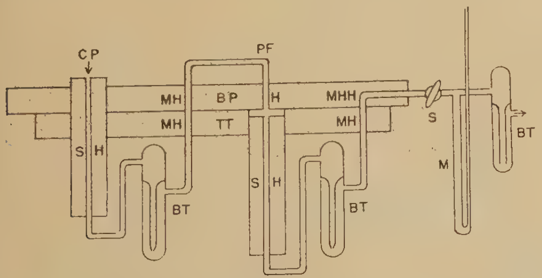

Fig. 5. Diagram showing the course of gas flow from the counting position *CP* to exit

BP, base-plate; *BT*, bubble trap; *H*, hole in base-plate; *M*, manometer; *MH*, matching holes in base-plate and turntable *TT*; *MHH*, horizontal matching hole in base-plate; *PF*, pre-flush position and connecting tube; *S*, stopcock; *SH*, sample holders.

ELECTRICAL CIRCUITS

The signal from the sample counter is first fed into a pre-amplifier (cathode follower circuit, 50 pF capacitor and 1 MΩ resistor) which is mounted on the side of the lead shield, before it is led into one channel of the anti-coincidence quench circuit. The anti-coincidence signal is carried directly in the shortest possible way into the other channel of the anti-coincidence circuit. The gate tube, type 6AS6, should be carefully selected since not all tubes are satisfactory. A potentiometer (10 kΩ) covering a range from −10 to −20 V was found very useful in the negative bias supply of the gate tube to adjust the proper bias voltage. At about −10 V all anti-coincidence signals pass through, while at about −18 V no signals pass through. The best bias voltage lies close to the middle of this range and must be found experimentally for each type 6AS6 tube. The final signal is carried in a coaxial cable to any ordinary scaler. Two separate stabilized high voltage power supplies are used to operate the anti-coincidence and sample counters in the Geiger region. The power for the pre-amplifier is taken from the scaler. A filter condenser should be built into the main anti-coincidence supply line and tested to determine whether various laboratory lights, switches and motors produce undesired pulses. Ground connexion of the common return and all chassis might be advantageous. Additional detailed information can be obtained from the authors.

COUNTER OPERATION

For proper operation of the counter it is most important to avoid any leaks in the flow system. The anti-coincidence ring and top counter should be checked for leaks by submersion in water while subjected to one pound of internal air pressure before assembly. The complete flow system can be checked with a vacuum manometer which is attached to the three-way stopcock or at the bottom of the sample holder in the counting position, or by accounting for the proper number of bubbles in the first and last bubble traps. The plateau length and the counting efficiency of all the counters are decisively influenced by the smallest leaks, even when considerable internal pressure is applied by adjusting the stopcock. The initial flushing time is greatly decreased by repeated evacuation at the bottom of the sample holder and refilling with Geiger gas. Finally an internal pressure of about $6\frac{1}{2}$ in. silicone oil is adjusted by a stopcock to a rate of about 20–40 bubbles per minute, corresponding to about 2–4 cm^3 of gas per minute. This pressure and bubble rate remain constant if there are no leaks in the system.

Since the counter is used only for low sample activities of a few counts per minute (maximum about 100 counts/min) long counting times are necessary. In this laboratory the counter is operated only overnight from about 4.30 p.m. to 9.10 a.m., pre-set for a time of 1000 minutes, leaving the scaler available for recording of more active samples during the day. A warm-up of about one hour is sufficient. After counting the sample or background, the sample holder is lowered and the next sample moved into position by turning the turntable counter clockwise (as viewed from above). The sample is raised into the sensitive volume and flushed until the counter is turned on. About thirty minutes flushing is sufficient.

For the construction of the counter and for trouble-shooting an oscilloscope is necessary to check signal heights and shape, noise of faulty parts, particularly tubes, and connexions. A second scaler is very useful to count uncancelled background or anti-coincidence signals simultaneously with the cancelled background.

COUNTER PERFORMANCE

It is desirable to check performance and plateau length of each of the eighteen side *AC* and the top *AC* counters separately, by counting the background without any top shielding. All counters are operated in the Geiger region. The starting potential of the eighteen *AC* counters is about 1050 V and that of both *AC* top counters (*RAC*, *CAC*) is about 1175 V. This difference in voltages causes the step in the plateau shown in curve *A* of Fig. 6 when all counters are connected. The useful plateau length of all *AC* counters extends from 1300 to 1600 V with a slope of about 1% per 100 V. The voltage for best cancelling is not critical and is adjusted at 1425 V in the present counter. The plateau of the sample counter extends from 1250 to 1600 V with a slope of about 0·5% per 100 V, and a setting of 1350 V is used. These plateaux and the counting rates of all counters are not significantly different within a gas back-pressure range fr
0 to 7 in. of silicone and a flushing rate of 20–66 bubb
per minute corresponding to 2–7 cm^3/min. [A much hig
flushing rate is necessary during the curing of the Armstro
cement (epoxy resin) even when the fast activator *A* a
heat are carefully used. It requires weeks to rid the ceme
of volatile compounds.]

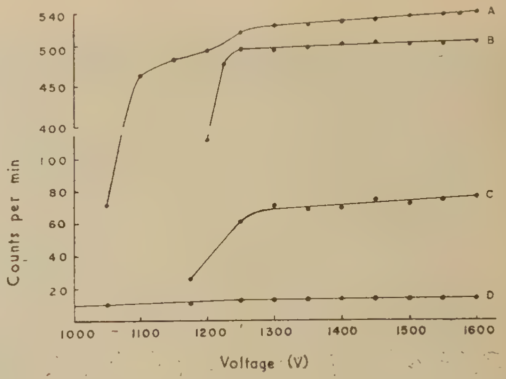

Fig. 6. Curve *A*, plateaux of all anti-coincidence counters; curve *B*, of sample counter; curve *C*, of both top (*RAC* + *CAC*) counters, and curve *D*, of top centre *CAC* anti-coincidence counter

In Tables 1 and 2 the effects of different shielding on t
background of the anti-coincidence and sample counters a
summarized. It can be seen that 2 in. of lead provid
sufficient top shielding if no unshielded γ-sources are prese
in the underground counting room, which has a concret
ceiling 6 in. thick with 15 in. of soil above. Increasing th
top lead shield from 2 to 4¾ in. does not decrease the bac
ground count. However, a 2 mc ^{60}Co source placed abov
the 2 in. top lead shield, 12 in. from the sensitive volume c
the sample counter, increased the cancelled backgroun
66·8 times, even with both mercury shields in place. Th
same ^{60}Co source, placed 6 and 12 ft away at the sam

Table 1. *Effect of mechanical and electrical shielding on the background (counts/min)*

	Background of anti-coincidence counters (counts/min)				*Background sample counters (counts/min)*			
	single side counter	*all 18 side counters*	*top Ac counters RAC + CAC*	*all AC counters*	*without AC counters*	*with 18 AC side counters*	*with top AC counter*	*with all AC counters*
Without any top shielding	36·9	497	70·0	524	6·86	2·82	4·26	1·559
With top 2 in. lead shield	29·1	332	48·9	340	6·08	2·13	4·29	1·123
With large 1 in. Hg shield	—	345	—	377	6·30	—	—	1·142
With small 1 in. Hg and 2 in. lead shields	—	331	48·0	348	6·11	—	4·18	1·050
With small and large 1 in. Hg and 2 in. lead shields	28·6	320	45·5	340	5·84	1·94	3·82	1·040
With small and large 1 in. Hg and 4¾ in. lead shields	—	307	—	326	5·73	—	—	1·043

Table 2. *Effect of 2 mc ^{60}Co on background counting*

	2 mc ^{60}Co					
	Horizontal distance				*Vertical distance*	
	12 ft		*6 ft*		*12 in.*	
Background counts	*counts/min*	*increase x*	*counts/min*	*increase x*	*counts/min*	*increase x*
Anti-coincidence	2048	6·17	5851	17·61	40960	123·40
Uncancelled in sample counter	8·53	1·43	16·50	2·77	103·0	17·3
Cancelled in sample counter	3·86	3·71	12·03	11·56	69·5	66·80

zontal level as the sample counter, increased the background 11·5 and 3·7 times. The maximum permissible amount of γ-radiation at a horizontal distance of 12 ft is therefore about 3·5 μc, which would give an increase of one standard deviation, 0·005 count/min.

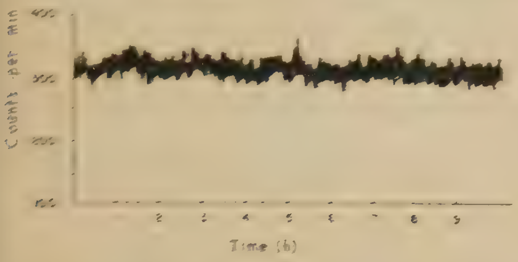

Fig. 7. Counting rate of anti-coincidence background

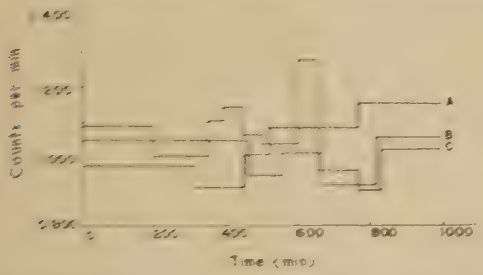

Fig. 8. Variation of counting rate of cancelled background in sample counter during the nights of 24 May (A), 28 May (B) and 29 May, 1957 (C)

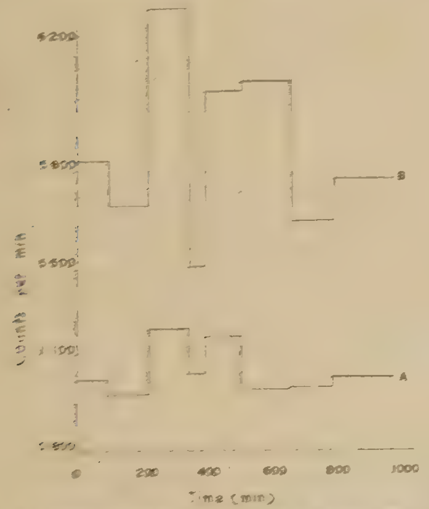

Fig. 9. Comparison of variation of cancelled, curve A, and uncancelled, curve B, background

A typical rate meter curve of background anti-coincidence graph of all AC counters over a ten-hour period is shown in g. 7. Fig. 8 shows the variation and change of counting tes during 1000 minutes on each of 3 nights (A, B, C). g. 9 compares the change of counting rates with cancelled and uncancelled background during 1000 minutes. It s interesting that rise and fall of cancelled and uncancelled ackground are not always parallel. The variations of total C, uncancelled and cancelled background and sample counts, re presented in Table 3. This shows that the background of he present counter is 1·040 counts/min, with a standard deviation of 0·005 counts/min (Kamen,(6) page 98, equation 10). ccepting a difference of five standard deviations as significant, the limit of sensitivity of the counter is 0·025 counts/min, providing enough counts are accumulated. The difference in the background between the present counter and the CE-14 Tracerlab counter is probably mainly due to natural contamination of the iron and copper used for the present sample holder and sample counter, rather than the Epon resin used in the CE-14 counter.

Table 3. *Variation of background and sample counting*

	Sample counter		
	1000 min background		
AC 10 min background (count/min)	*uncancelled (count/min)*	*cancelled (counts/min)**	*10 min ^{14}C sample (counts/min)*
335·1	5·973	1·049	489·9
335·2	5·915	1·031	498·9
325·7	5·810	1·023	502·9
332·5	5·951	1·034	510·7
330·3	6·020	1·065	494·5
328·5	6·099	1·061	480·4
336·7	6·037	1·040	504·8
321·1	5·998	1·016	494·1
342·0	6·043	1·041	489·6
333·2	5·627	1·040	489·9
332·0 ± 2·0	5·947 ± 0·005	1·040 ± 0·005	495·6 ± 2·7

* Counted during ten consecutive nights from 21–30 May, 1957.

The efficiency of the low background counter was measured by counting a "weightless" sodium benzoate-^{14}C standard (12 μg/cm^2) obtained as the free acid from Isotopes Specialities Co. Inc., Burbank, California, and found to be about 62%. This high efficiency is obviously due to backscattering of the steel planchets, as already pointed out by Christian and others.(7) Using the same samples it was found that the efficiency of the authors' Tracerlab 2 π flow counter is about 45%.

A comparison of the efficiency of the new Tracerlab CE-14 low background end-window counter ($C1$) with that of the present flow counter ($C2$) leads to the following conclusion: the efficiency of an end-window counter is normally about 50% of that of a 2 π flow counter; however, owing to improvement in the construction, the efficiency of $C1$ is considered to be about 70% or about 31·5% absolute, assuming that both reference 2 π flow counters had the same efficiency of about 45%. The background of $C1$ is about 0·6 counts/min and that of $C2$ is about 1·0 counts/min. According to considerations of Thomas,(8) it is useful to calculate the factor of merit Mo when comparing counters. It is defined as "the ratio of counting time for $C1$ to the counting time for $C2$ for equal statistical accuracy."

$$Mo = (Rs_2/Rs_1)^2(R_{B1}/R_{B2})$$

where Rs_1 and Rs_2 and R_{B1} and R_{B2} are the mean net sample and background counting rates of two counters. This equation leads in the case of the two counters in question to

$$Mo = (62/31\cdot 5)^2(0\cdot 6/1\cdot 0) = 2\cdot 3$$

Therefore, in spite of the higher background, the present flow counter requires, owing to its high efficiency, less than half as long as the Tracerlab CE-14 flow end-window counter to record any counting rates to the same statistical accuracy.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. M. D. Kamen for helpful discussions, Dr. J. M. Cameron for many valuable suggestions and Mr. D. C. Anderson for preparing the photographs.

They are grateful to Tracerlab Inc., California Division, for information and background data on the CE-14 counter.

The design of this circuit was kindly supplied by Atomic Energy of Canada in Chalk River (circuit No. A.E.P. 1703 and power supply No. A.E.P. 1116).

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Transmission specimen holder for electron diffraction

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[*Paper received* 11 *August*, 1958]

A specimen stage for electron diffraction and electron shadow microscopy has been constructed, to enable a holder containing two transmission specimens to be inserted into, or withdrawn from, the specimen chamber without breaking the vacuum in the system. The time required to change specimens is less than one minute. Controls are provided to give specimens two independent translations in a plane normal to the electron beam and a rotation about the axis of the holder.

INTRODUCTION

In electron microscopes and electron diffraction cameras, it is common practice to include air-locks so that specimens or photographic plates may be changed without admitting air to the main column of the instrument. If the internal volume of the equipment is relatively large, the time for change-overs can thus be considerably reduced. A particularly favourable situation arises in the case of specimens for examination by transmission methods. Here the specimens are generally small, and hence afford an opportunity for incorporating in the specimen holder an air-lock in which, by suitable design, the volume of air at atmospheric pressure that is admitted to the microscope or diffraction camera with each exchange of specimen can be reduced to only a few cubic millimetres. In these circumstances it is not necessary to isolate the diffusion pump and complete recovery of the high vacuum can be attained in a few seconds.

The specimen stage described below has been designed for use with a high-resolution electron diffraction camera, with the following four main requirements in view:

(1) Facilities to enable two transmission specimens to be inserted simultaneously into the camera, with the admission of a minimum quantity of air.

(2) Means for displacing the specimens relative to the electron beam, so that a given region may be located precisely and examined. In addition, for some electron diffraction work it is also desirable to provide an independent rotation of the specimen about an axis normal to the beam.

(3) Any greased or oiled seals to be avoided or kept well away from the specimens, in order to reduce the risk of contamination.

(4) Lastly, since the stage is intended only for transmission studies by selected-area electron diffraction or electron shadow microscopy, it is essential that it should be readily removable from the specimen chamber to permit another holder to be inserted for reflexion work.

The type of air-lock adopted is similar in general princip to that employed in a commercial electron microscope.†

THE APPARATUS

The complete stage is illustrated in the figure, which show a cross-section of the assembly in a plane perpendicular t the electron beam. It consists of three main sections and ha been designed to be housed in two diametrically opposit ports in the specimen chamber.

The brass block *A* carries a spindle *B* which passes through a Wilson seal‡ and whose axial movement is controlled by micrometer *C*. The flange of *A* sits on a shoulder in a reces in the port of the specimen chamber, a vacuum seal being made by a flat Neoprene gasket which is compressed by the clamp ring *D*.

The main unit of the stage is attached to another brass member *E*, which is sealed into a second port in the specimen chamber in a similar fashion to *A* (not shown in the diagram). The left-hand end of this unit pivots on the spindle *B* and is held firmly in contact with it by atmospheric pressure on the circular plate *F*, which is brazed to the cylindrical brass tube *G* and the metal bellows *H*. The tube *G* is soldered to another brass tube *I*, which is square in section at its right-hand end and slides laterally between two steel guide plates *J*. The movement is controlled by a second micrometer *K* and the spring-loaded plunger *L*.

The removable specimen holder consists of a Monel spade *M*, which is attached by means of a Monel rod, carrying a spring-loaded Neoprene seal *N*, to a cylindrical block *O* and a graduated drum *P*. As shown in the enlarged section, the flat spade *M* contains two circular recesses machined to house two $\frac{1}{8}$ in. diameter specimen grids (as used for electron microscopy), which are held in the spade by the Monel circlip *R*. The spade is inserted into the camera through a rectangular slot in the block *S*, which is soldered into the tubes *G* and *I*. A spring-loaded piston *T* carries a

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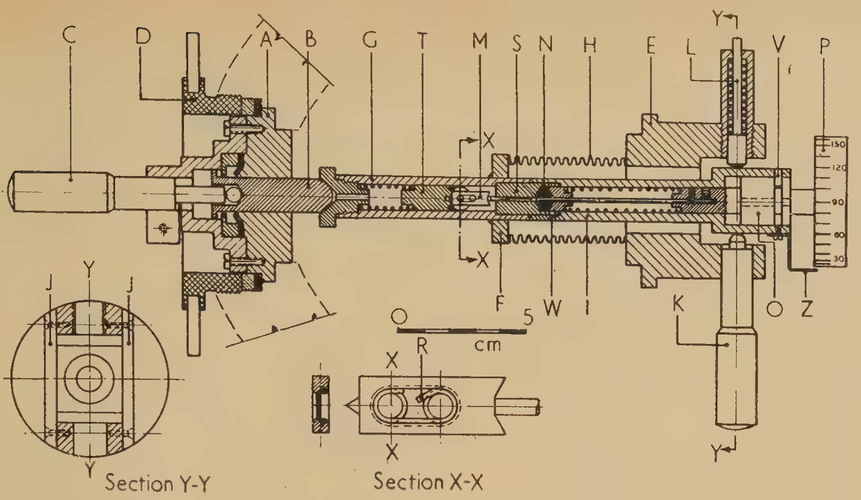
† VAN DORSTEN, A. C., NIEUWDORP, H., and VERHOEFF, A. *Philips Techn. Rev.*, **12**, p. 33 (1950).

‡ WILSON, R. R. *Rev. Sci. Instrum.*, **12**, p. 91 (1941).



General assembly of specimen stage

small O-ring which is thrust against the face of the block *S* when the holder is removed from the stage. Circumferential and longitudinal grooves are machined in the block *O* to accommodate a locating pin *V*, fastened into the end of the tube *I*. During initial assembly of the holder, a jig was used to position accurately the spade *M* with respect to the block *O* in order to ensure that when the pin *V* is in the longitudinal groove in the block, the spade is in the correct orientation to slide smoothly through the close-fitting slot in the block *S*.

To insert the holder into the stage, the drum *P* is turned through 90° relative to the position shown in the diagram, so that the locating pin may engage the longitudinal groove in the block *O*. As the spade *M* slides into the slot in the block *S*, the spring-loaded seal *N* is thrust firmly against the right-hand mating face of the block *S before* the spade breaks the seal between the plunger *T* and the inner face of the block. (The reverse action occurs when the spade is removed.) A small hole *W*, drilled close to the seat of the seal *N*, ensures that no trapped or compressed air is forced into the camera during this operation. The holder is pushed into the stage until the locating pin meets the circumferential groove in the block *O*. The drum is then rotated through 90° as indicated by the pointer *Z*. In this position the left-hand specimen in the spade is normal to the electron beam and in line with two holes drilled in the tube *G* to provide free passage for the incident and diffracted beams. The specimen can be scanned by manipulating the two micrometers, and rotated up to a maximum useful angle of $\pm 60°$ relative to its normal position, by means of the drum *P*. To examine the right-hand specimen, the holder is turned until the pin *V* again engages the longitudinal groove in *O*, pushed in a further $\frac{1}{8}$ in. and then rotated so that the pin bears against the outer face of the block.

The stage may be interchanged with another holder for reflexion work by removing the block *E* and its assembly from the specimen chamber, leaving the body *A in situ*.

PERFORMANCE

This unit has been in operation for over one year in an instrument used jointly for high-resolution electron diffraction, selective-area diffraction and electron shadow microscopy. The specimen controls have proved to be smooth and positive and no drift has been observed for shadow microscopy, at least up to magnifications $\sim 7000\times$. In the particular camera in which the stage is used, a vacuum gauge attached to the main column of the camera indicates a pressure rise from $\sim 5 \times 10^{-5}$ to $\sim 5 \times 10^{-4}$ mm of mercury immediately after insertion of a specimen, followed by complete recovery of the vacuum in 3–5 s. Owing to the very small amount of air admitted through the air-lock, specimens do not appear to suffer any damage when subjected to the rapid change in pressure from atmosphere to the high vacuum condition in the camera.

ACKNOWLEDGEMENTS

The authors are indebted to several members of the staff of the Drawing Office at Aeronautical Research Laboratories for helpful advice and suggestions on the design of the stage, and to the Chief Scientist, Australian Defence Scientific Service, Department of Supply, Melbourne, Australia, for permission to publish this paper.

Laboratory and workshop notes

Method for filling capillary pipettes with mercury for calibration purposes

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[*Note received* 24 *October*, 1958]

A recent note* in this *Journal* indicated a method of ensuring that when an opaque capillary tube is filled with mercury for volume or diameter calibration the tube is truly full, no air being left between the terminal mercury menisci and the closing end-plates. Owing to capillary forces it is not easy to ensure this. The difficulty referred to also arises in the calibration of fine capillary pipettes, but in this instance it is complicated by the need to set one end of the mercury thread precisely to a graduation line remote from the ends of the tube instead of to a terminal plane. The method described below was devised by the author many years ago and is still used at the National Physical Laboratory with entire satisfaction. In the apparatus shown in Fig. 1, which was made up very quickly with materials which happened to be readily to hand, the wooden member *A*, pivoting freely about *B*, holds the pipette *C* vertically by means of a cylindrical hole near its end, with the tip of the jet resting on a fine-textured wooden pad *D* attached to the end of an appropriately bent piece of $\frac{1}{2} \times \frac{1}{16}$ in. strip-iron. The strip-iron is also pivoted freely at *B* and rests against the screw *E*.

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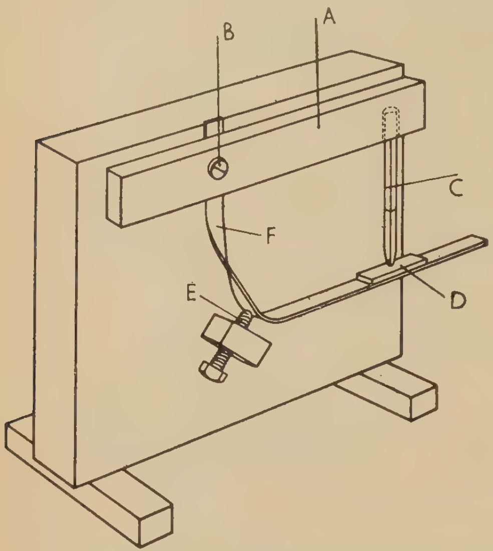

Fig. 1. Apparatus for filling capillary pipettes with mercury for calibration between the tip of jet and the graduation mark; operating position

The pipette, held nearly horizontal by hand, is first filled to excess from mercury in a watch glass by suction, using an auxiliary flexible tube. At this stage the jet need not remain full and it is fairly easy to ensure that the mercury remains in the pipette. Still held horizontal, its suction end is then inserted into the member *A* which has been brought to vertical as indicated in Fig. 2; the pad *D* is then brought up to the jet, whereupon the assembly is rotated as a whole until the iron strip rests against *E*. During this operation the increasing hydrostatic head exerted by the mercury column expels the air from the jet; in the final stage the mercury completely fills the bore of the jet, right up to the pad *D*, against the back-pressure due to capillary forces. The mercury does not then escape because the hydrostatic pressure is insufficient to force it between the tip of the jet and the pad, the gap being too narrow, the surface tension of the mercury too great and the angle of contact too large. Provided, therefore, that there is initially enough mercury in the pipette, the upper end of the mercury column remains above the graduation line.

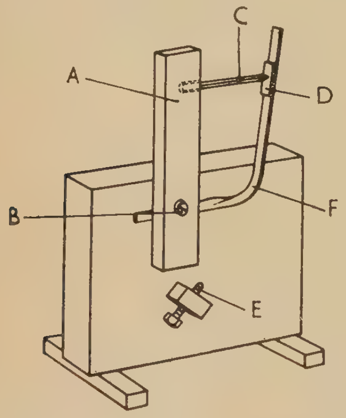

Fig. 2. Assembly and removal position

The iron strip is then tapped from above, near to its horizontal end (a lightly held pencil is a convenient and suitable means) whereupon the inertia of the pipette causes it to separate momentarily from *D* and small globules of mercury escape from the jet. The size and the number of the escaping globules depends on the vigour and rate of tapping; the descent of the upper mercury surface is consequently under full control. Moreover, the jet remains completely full of mercury throughout.

When the mercury meniscus has reached the desired position in relation to the graduation line, tapping is discontinued while the meniscus position is checked at leisure. Finally, the pipette is grasped between *A* and *D* and brought to the horizontal again (see Fig. 2), when it is removed and the mercury is weighed with or without the pipette.

The purpose of the screw *E* is to provide the necessary adjustment for pipettes of the different lengths encountered in practice.

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Valve for pressures of 10 kilobars*

By E. Whalley, B.Sc., Ph.D., A.R.C.S., and A. Lavergne, Division of Applied Chemistry, National Research Council, Ottawa, Canada

[*Note received* 1 *August*, 1958]

A valve which will work well at pressures of the order of 10 kb or higher does not seem to have been described in detail, though the Harwood Engineering Co. Inc. can supply a valve rated for 200 000 lb/in.^{2} A good valve must have a reliable packing and the stem must be easy enough to turn under the maximum pressure so that the contacting of needle and seat can be easily felt by the hand. If it could not be felt then the seat of the valve would be easily spoiled by over-tightening. In valves of conventional design a stem with a cone at the end is pushed, by turning a screw thread, through a pressure seal so that the cone closes a hole. If there is a high pressure in the valve, work must be done in displacing the pressurized fluid and in overcoming the friction of the packing. Because a screw thread is mechanically very inefficient, the amount of work which must be done to overcome the pressure of the fluid and the friction in the screw thread and packing is very high indeed. Such valves usually have very little "feel" left at pressures above a few kilobars.

The authors have tried to overcome these difficulties in the following way. First, the screw thread which drives the needle is within the high pressure region. This ensures that the load on the screw thread, and hence the friction in it, during the closing of the valve is low, the only important force being that necessary for the cone to seat properly; no work need be done against the high pressure because the valve can be closed by merely rotating a shaft in the packing. Second, a ball bearing is used to take the force on the stem due to the pressure. This reduces the bearing friction and hence the torque required to turn the shaft. Third, an O-ring is used as the pressure seal of the shaft, and the shaft is kept as small as possible. This further reduces the torque required to turn the shaft.

The valve is shown in the figure. Part (1) is the shaft which rotates in the O-ring packing. The load on the shaft aused by the pressure is taken by the ball bearing and by land nut (2). Gland nut (4) holds the whole of this part in he body (9) of the valve. Parts (3) and (5) are lock nuts or gland nuts (2) and (4) respectively. Part (7) is a follower or the O-ring; the clearance between it and the body is maller than the clearance between it and the stem, so that t cannot bear on the shaft. Part (6) is a hardened steel late which carries the load caused by the pressure and ransmitted through the follower. The needle (8) is attached to the stem (1) by means of a screw thread. The needle is non-circular and it is in a non-circular hole so that it cannot rotate; by turning the shaft the needle can be advanced or retired. A section *A–A* through the needle is shown enlarged in inset (*a*). The hole in the valve was made by drilling a small hole on one side of the centre line and then drilling the main hole. A number of other methods of preventing the needle from rotating can also be used. In order to increase the "feel" of the valve the thread of the needle is a two-start thread size $\frac{3}{16}$ in., 16 turns/in., and it is left-hand to ensure that, as usual, clockwise rotation of the shaft advances the needle. A weep hole was drilled in the shaft just above the thread.

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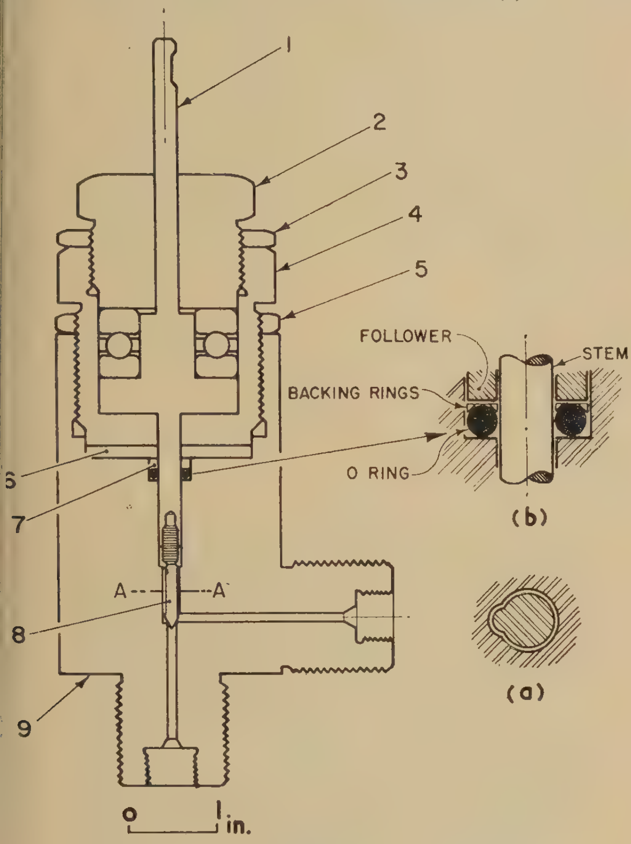
* N.R.C. No. 5007.



Valve for 10 kb

Inset (*a*) Section A–A enlarged. *Inset* (*b*) O-ring seal.

The O-ring seal is shown in detail in inset (*b*). The extrusion of the O-ring is prevented in a manner very similar o that described by Daniels and Hruschka.* Small rings made of ¾-hard phosphor-bronze and having a triangular cross-section are used. It is not necessary to cut away the ear of the ring to get a good seal and there is no tendency or the triangular ring to stick in place.

The material used for the body, needle, follower and plate (7) is AISI 4340, aircraft quality (MIL-S-5000), heat treated to a hardness of 52–54 Rockwell C (ultimate tensile strength 260 000–280 000 lb/in.^{2}). The stem is made of Jessup's superior oil-hardening steel and heat treated to 58–60 Rockwell C. Both gland nuts were made from annealed AISI 4340. The O-rings were 90 Shore A hardness.

This valve behaves very well at pressures up to 10 kb and the authors have no reason to think that a similar design could not be used for higher pressures. The torque required to turn the stem at 10 kb pressure is 3 ft lb and the contacting of the needle with the seat can be very easily felt.

The connexions to the valve can, of course, be made in any manner desired. Those illustrated were used by the authors in order to fit equipment they already had, and it is not implied that they are the best.

O-ring seals for pressures of 10 kilobars*

By E. Whalley, B.Sc., Ph.D., A.R.C.S., and A. Lavergne, Division of Applied Chemistry, National Research Council, Ottawa, Canada

[*Note received* 1 *August*, 1958]

O-rings have often been used to seal high pressures. They have many advantages as sealing rings, of which the most important are ease of assembly and disassembly and availability in a wide range of sizes and at low cost from commercial sources. One of the most useful designs that has been described is the modification of a design due to Lawson† that was made by Daniels and Hruschka.‡ Lawson described the use of two O-rings in series to seal the piston of a 10 kb intensifier. Daniels and Hruschka used only one O-ring and backed it by means of a bronze ring of triangular section. The purpose of the bronze ring is to reduce the extrusion of the O-ring into the gap between the piston and cylinder. The effect of 10 kb pressure on the gap between a ¾ in. diameter piston and cylinder is to increase it by about 0·005 in. On release of pressure this gap closes and part of the O-ring tends to be pinched off, so causing fairly rapid failure. The authors have also used backing rings similar to those described by Daniels and Hruschka and made of ¾-hard phosphor-bronze, and have found them extremely satisfactory. Unlike Daniels and Hruschka, however, the authors found that a right-triangular section for the backing ring was quite satisfactory and that the backing rings had no tendency to stick where they seal.

The purpose of this note is to describe other O-ring seals that have been used up to 10 kb by the authors; they can probably be used to higher pressures. It is not always convenient to use metal backing rings, particularly if a connexion is fairly large and is to be made and broken very frequently, because there is always a danger that when assembling the apparatus the very fragile metal ring will be broken. The authors have, therefore, frequently used the seal depicted in Fig. 1. The fit between the plug and the bore is usually close to A.S.A. class 3. By making the plug hollow for a short distance past the O-ring the gap between the plug and the bore can be made to decrease rather than to increase with increasing pressure. In order to reduce fatigue it is well to have a spherical radius at the bottom of the hole. Because the seal is entirely self-sealing the gland nut that supports

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* Daniels, W. B. and Hruschka, A. A. *Rev. Sci. Instrum.* **28**, p. 1058 (1957).

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* N.R.C. No. 5006.

† Lawson, A. W. *Rev. Sci. Instrum.*, **25**, p. 1136 (1954).

‡ Daniels, W. B., and Hruschka, A. A. *Rev. Sci. Instrum.*, **28**, p. 1058 (1957).

the plug needs no preloading and can be tightened to only finger tightness, and likewise it can be loosened very easily. At pressures of the order of 10 kb the O-ring lasts much longer than the two O-rings of Lawson, but not so long as the backed-up O-ring of Daniels and Hruschka. If the head of a vessel is sealed in this manner and if the gland nut has an interrupted or a strongly tapered thread, i.e. a breach-block thread, the vessel can be assembled and disassembled very quickly. Such seals are good at moderate pressures to quite high temperatures. For example, seals of $1\frac{1}{4}$ in. diameter have been used in this laboratory up to 160° C at pressures of 3 kb without detectable (1%) loss of pressure over several days.

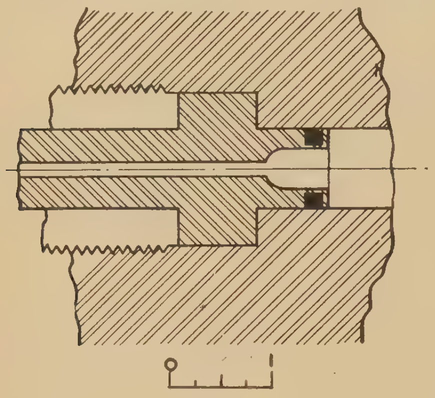

Fig. 1. O-ring seal

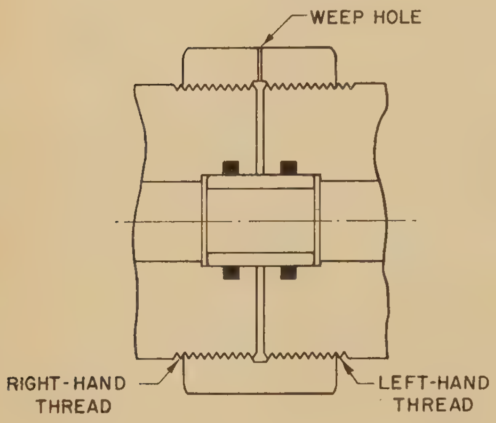

Fig. 2. O-ring seal

A second seal the authors have used based on the same principle is depicted in Fig. 2. The fit between the sealing cylinder and the bore is usually close to American Standards Association class 3. Pressure closes the gap between the sealing cylinder and the bore and so prevents extrusion of the O-ring. The life of the O-ring is several tens of applications of pressures of 10 kb at room temperature. An advantage of this seal is that the two halves of the vessel can be set at various distances apart, the main limit to this being that the sealing cylinder shall not burst into the space between the two halves of the vessel. This limit can be overcome and a large relative motion obtained by making a number of sections of vessel of different thickness and putting them between the two halves in order to support the sealing cylinder. This seal can be used with a right-hand thread on one-half of the vessel and a left-hand thread on the other half. The two parts can then be pulled together by means of a turnbuckle without relative rotationary motion. This may be advantageous sometimes.

The O-rings used have always been the hardest available commercially, with a hardness of 90 Shore A.

Labyrinth radiation trap for use with standard X-ray diffraction equipment

By O. Kennard, M.A., A.Inst.P., A. J. P. Martin, F.R.S., and L. Woodget, National Institute for Medical Research, Mill Hill, London N.W.7

[*Note received* 20 *August*, 1958]

In recent years increasing attention has been directed to the need for providing adequate protection against ionizing radiation. In many laboratories, where standard X-ray diffraction equipment is used, serious leakage of X-rays can occur between the X-ray tube face and the beam collimator. This is particularly serious when, in order to foreshorten the X-ray target, the collimator is made to incline several degrees to the tube face. To prevent such leakage a labyrinth-type trap was designed which can be attached permanently to standard X-ray diffraction apparatus, and which at the same time permits optimum alinement of the apparatus and X-ray beam.

Two such traps* for use with a Unicam single-crystal goniometer and a Unicam Weissenberg goniometer respectively are illustrated in Figs. 1 and 2. Each of the traps consists of two mild-steel blocks in which annular grooves about a quarter of an inch deep, are machined. The sets of grooves are arranged to form a labyrinth when the two halves are fitted together. The grooves are wide enough to allow for the relative orientation to be varied by several degrees.

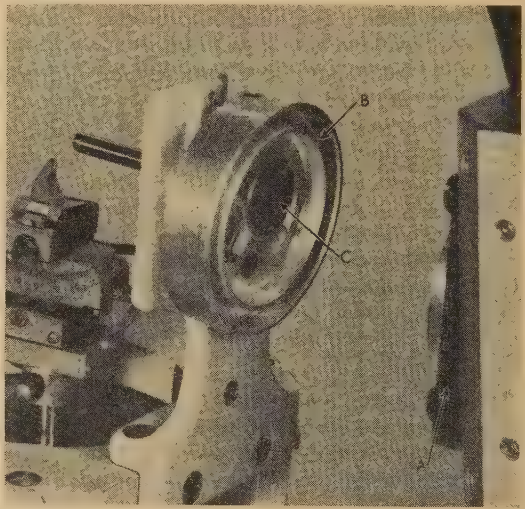

Fig. 1. Radiation trap fitted to Unicam single-crystal goniometer

In the case of the single-crystal goniometer (Fig. 1), one-half of the trap *A* is machined with the back plate at an angle of 6° to the horizontal. This part is permanently attached to the X-ray tube housing; the other half *B* is carried by the collimator support. The standard collimator has to be fitted with a thin end-flange *C* of three-quarters of an inch diameter in place of the usual beam trap, to prevent stray radiation eaching the camera over the top of the collimator. It may e worth mentioning that an all stainless steel collimator has roved more robust in use than the standard brass one rovided by the makers.

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* Full working drawings are available, on loan, to anyone interested.

The two halves of the trap illustrated in Fig. 2 are both ermanently attached to the collimator support of the

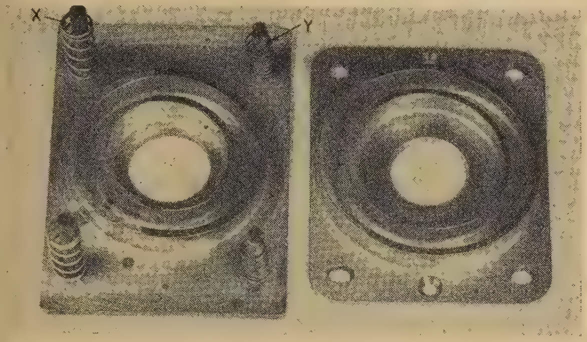

Fig. 2. Radiation trap for use with Weissenberg goniometer

Jnicam Weissenberg goniometer. The back plate is held in ontact with the X-ray tube housing by the springs *X* and *Y* and with normal usage no radiation leak is detectable. o allow for the angle of inclination the ring-faces are each nachined at an angle of 3°. With this arrangement, no nodification of the standard collimator is necessary.

Alinement of the cameras and X-ray beam can be carried ut in the usual way through the adjusting screws provided vith the instruments. The design of the trap does, however, revent gross misalinement of the goniometers, and ensures hat once set the cameras are always placed a standard listance from the X-ray tube. Some teaching laboratories nay find this an advantage.

Method for breaking open sealed electronic devices in vacuo

By M. G. Charlton, Ph.D., and G. M. C. Perkin, The Mullard Radio Valve Co. Ltd., Mitcham Junction, Surrey

[*Note received* 23 *July*, 1958]

n laboratories serving the electronic industry it is sometimes equired to analyse the residual gases in valves and cathode-ay tubes. Analysis of such small quantities of gas is possible with the mass spectrometer, but the problem of extracting the gas, without contamination, by breaking the glass envelope *in vacuo* has remained without an entirely satisfactory solution. Dropping a magnetically raised, pointed rod on to a valve has limited success but the shock of the impact entails some risk of breaking the vacuum system. The method* of enclosing the valve in an evacuated soft copper tube, attached to a bubble breaker, and breaking by squeezing the tube in a vice, is only applicable to small valves and entails a fair amount of preparation. The method to be described is very versatile, entails no risk of damage to the vacuum system, and has been much used in this laboratory with complete success.

A description of the application of the method for breaking a miniature valve will illustrate the basic principle (see Fig. 1). *A* and *B* are mild steel rods, fitting snugly in the glass side arms. The lower rod has a detachable, shaped nose piece (a knife edge in the present example), which, when the solenoid *D* is energized, strikes the side of the valve. The upper rod, which is attached to a shaped anvil, has the solenoid *C* positioned so that when it is energized the rod experiences a downward pull and therefore acts as a shock absorber for the impact of the "bullet." The solenoids are energized simultaneously and momentarily, and the valve receives a very powerful, sharp blow. The slight shock of the "bullet" falling back to the rest position is taken by a small spring.

The solenoid coils are made by winding 1500 turns of 26 s.w.g. enamelled copper wire on a 1 in. diameter former over a length of 1¾ in., and are run in series on 110 V d.c.

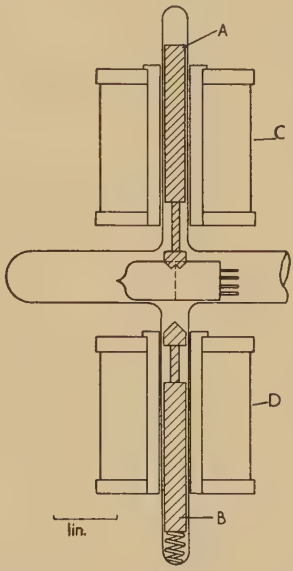

Fig. 1. Application of breaker for opening a valve *in vacuo*

They are considerably over-run and they would quickly become hot if in use continuously, but in practice they are only ever operated momentarily and do not even warm up.

In the case of the application illustrated in Fig. 1, it is advantageous to make around the valve envelope a light file mark which is alined with the knife edge. It has been found possible, by carefully adjusting the position of the lower solenoid, to open a valve envelope without damaging at all the electrode structure. Thus, by taking out connexions from the valve pins through a multi-lead seal it is possible to operate a valve and at the same time to investigate any gas evolution that occurs. Miniature valves with pressed glass bases have also been opened by puncturing the base with a very sharp, hardened steel point. This technique is preferable if the activity of the getter film in a sealed valve is to be

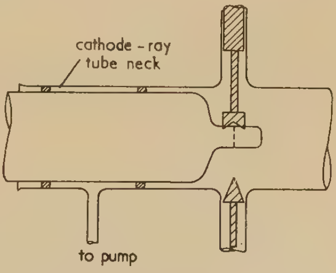

Fig. 2. Arrangement used for opening a cathode-ray tube *in vacuo*

measured, for the glass carrying the barium deposit is not shattered.

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* Norton, F. J. *Rev. Sci. Instrum.*, **26**, p. 238 (1955).

Cathode-ray tubes may be opened at the pumping stem using the arrangement shown in Fig. 2. The outer glass tube must be a fairly tight sliding fit over the O-rings, in which case the vacuum lock between the O-rings ensures a very low leak rate. It is necessary to make a file mark on the pumping stem. Glass tubes up to 10 mm external diameter have been broken by this method. Even the metal envelope of a small germanium power diode has been successfully pierced using a fine, hardened steel needle point. Another more unusual application of the method was to shatter the glass beading on tungsten wires in order to release, for analysis, the gas bubbles trapped in the seals.

We wish to thank Dr. J. A. M. van Moll, Head of the Material Research Laboratory, and the Directors of the Mullard Radio Valve Co. Ltd., for their permission to publish this note.

Experimental determination of effective bandwidth of monochromators

By I. Chavet, M.Sc., Ministry of Defence, Tel-Aviv, Israel

[*Note received* 27 *June*, 1958]

For the rational use of any monochromator, the effective bandwidth $\Delta\lambda/s$, where s is the slit width in millimetres, must be known for every wavelength; its determination over the whole range of wavelength is admittedly rather tedious. A simple solution of the problem can be achieved in the following way. The ratio $\Delta\lambda/s$ can be written thus:

$$\Delta\lambda/s = (\Delta\lambda/\Delta\alpha)(\Delta\alpha/s)$$

where α is the angular position of the wavelength drum. The function $(\Delta\lambda/\Delta\alpha)_\lambda$ is the derivative of the helical scale engraved on the wavelength sleeve of the monochromator and can thus be measured simply and rapidly for any prism on the corresponding sleeve. The ratio $\Delta\alpha/s$ is characteristic of the design of the monochromator; it is independent of the material of the prism and practically independent of the position of the wavelength drum. This is the only constant which need be determined optically, using the monochromator. To this end, the exit radiation is measured as a function of the rotation of the wavelength drum in the neighbourhood of a mercury line, when one slit has a width s and the other is almost closed. Fig. 1 shows one such curve. The half-intensity bandwidth in angular units is the $\Delta\alpha$ corresponding to the slit width s.

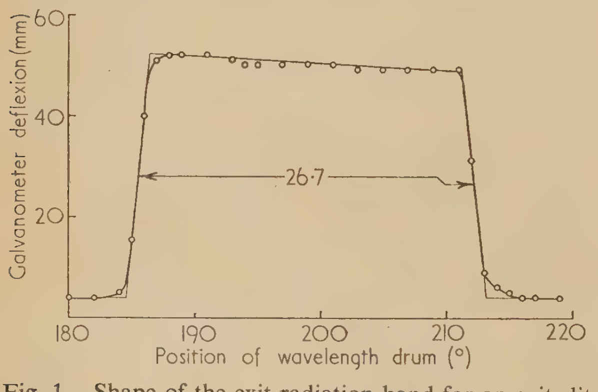

Fig. 1. Shape of the exit radiation band for an exit slit width of 0·50 mm

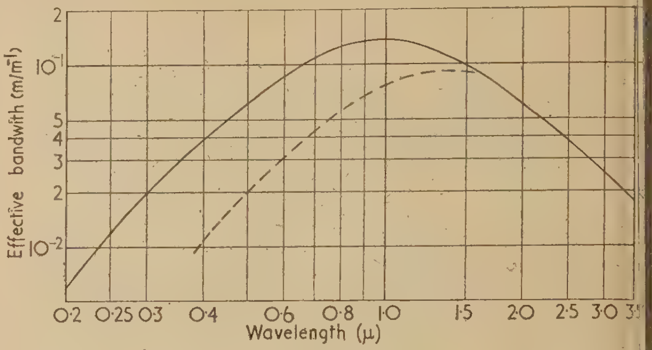

Fig. 2. Relative bandwidth $\Delta\lambda/\lambda\,.\,s$ for the quartz and glass prisms of the Hilger large-aperture monochromator, where s is the common slit width in millimetres

——— = quartz prism. — — — = glass prism.

For example, the constant $\Delta\alpha/s$ measured for the entrance slit of the Hilger large-aperture monochromator (mod D247) was found to be 54·1°/mm. The exit slit gave th value 56·1°/mm. The function $\Delta\lambda/(\lambda\,.\,s)$ for the quartz an glass prisms, determined in this manner, is represented b the curves in Fig. 2. This function was chosen in preferenc to $\Delta\lambda/s$ since

$$|\Delta\lambda|/\lambda = \Delta\nu/\nu = \Delta E/E$$

ν being the frequency and E the quantum energy of the radiation concerned.

Automatic protecting switch for water-cooled compressors

By J. K. N. Sharma, M.Sc., Indian Association for the Cultivation of Science, Calcutta, India

[*Note first received* 1 *July, and in final form* 11 *August*, 1958]

A positive system of water circulation must be used with all types of water-cooled compressors (single, double or multi-stage) to protect the compressing system from damage, due to the excessive amount of heat generated during compression. A few switches of this type may be available in the market, but a switch simple in principle and design is being described here.

The present arrangement is designed to make or break an electric circuit when the flow of liquid in a pipe reaches a predetermined minimum and therefore can be used as a protective device with apparatus using the liquid as a coolant. This may have to be supplemented by suitable relays where high electric currents are to be interrupted. The instrument through which there is an actual flow of liquid, functions entirely independently of static pressure, and it may be so arranged that the contacts operate when any desired flow conditions are attained.

The whole assembly may be described in two parts: (1) flow regulator (Fig. 1); and (2) (electrical) circuit-breaker. The flow regulator is connected to pressure tappings as shown in Fig. 2. When the flow occurs, the water enters the inner brass cylinder *A* through *I* (Fig. 1) and leaves it through the opening *O* at the bottom finally escaping through the annular space out to the exit *E*. By raising or lowering the plate *P* with the help of the knob *K*, the float *F* can be raised or lowered, any leakage of the coolant through the stem of *K* being prevented by the gland packing *G*. When the rate of flow is more than the predetermined minimum, the float *F* is sufficiently raised, thereby listing the glass-mercury switch and completing, with the help of a pellet of mercury, the electrical circuit through the tungsten leads *T*. These leads are connected to an electric circuit for starting or stopping the motor of that compressor which uses this liquid as coolant. Fig. 2 shows the method of connecting the flow regulator to the circuit-breaker which is of solenoid and plunger type, in which the plunger carrying the switch contacts is attracted into the solenoid as current is allowed to pass through the coil, thereby completing the circuit.

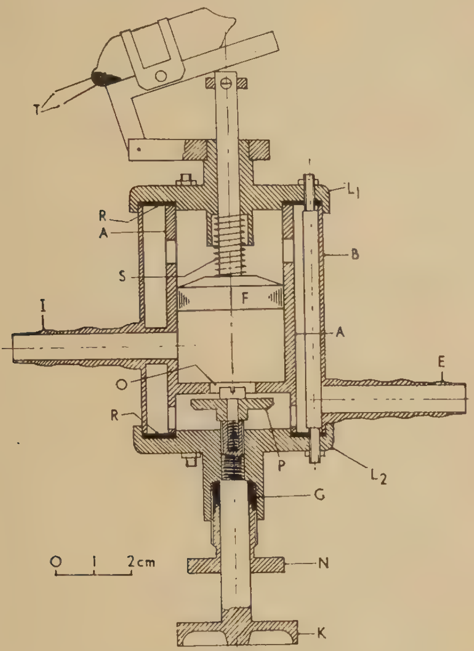

Fig. 1. Flow regulator

A, inner brass cylinder; *B*, outer brass cylinder; L_1, L_2, lids to outer brass cylinder; *R*, rubber gaskets to make *B* water-tight; *F*, brass float; *S*, spring; *I*, water inlet; *O*, outlet for water; *E*, final exit; *P*, brass plate; *K*, knob for adjusting the flow of water; *G*, gland packing to prevent leakage of water; *N*, gland nut; *T*, tungsten leads to glass mercury switch.

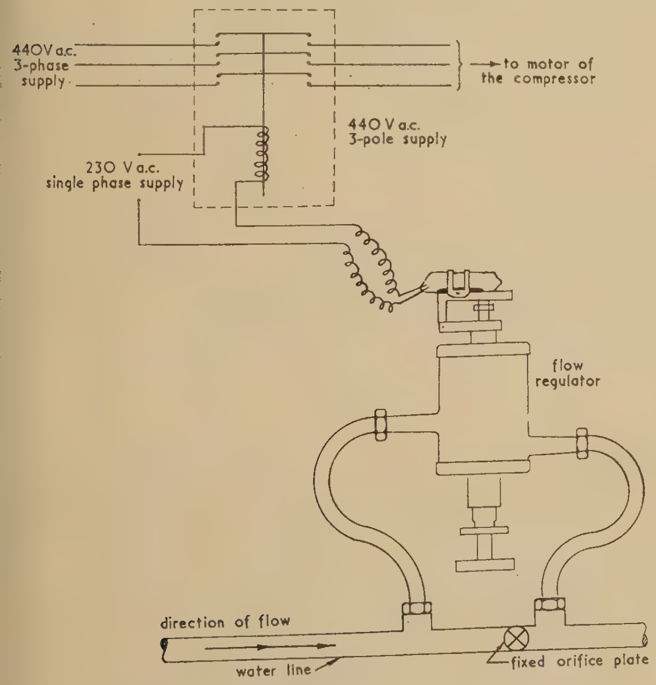

Fig. 2. Flow regulator in position

The knob *K* is adjusted for a desired rate of flow, and so long as the rate of flow exceeds that, the float *F* is kept raised and hence the motor remains connected to the supply line. When the rate of flow falls below the desired value, the spring *S* in the stem of the float *F* pushes the float down, and the mercury-switch is tripped down disconnecting the solenoid coil from the mains. The iron core of the coil is demagnetized and in turn releases the 3-pole plunger, thereby disconnecting the compressor motor from the supply. The switch can be adjusted for any rate of flow between $\frac{1}{4}$ l. and 5 l./min, but it can carry up to about 10 l./min when there is some leakage of the liquid through the stem of the float. No gland packing has been used around the stem transmitting the movement of the float to the switch and consequently a very small amount of leakage may occur if the flow exceeds 5 l./min.

In this way the arrangement can be used as an automatic switch for protecting a compressor from the damage consequent on the failure in the supply of water. The layout of the whole assembly can be easily followed from Fig. 2.

The author wishes to express his thanks to Prof. B. N. Srivastava and Mr. A. K. Batabyal for their helpful discussions.

An oscillating-plate differentiator for spectrophotometry

By I. G. McWilliam, B.Sc.(Hons.), A.R.A.C.I.,
Imperial Chemical Industries Ltd., Blackley,
Manchester 9

[*Note received* 18 *August*, 1958]

Several methods have been reported for producing derivative spectra, and these can be divided into two groups—electrical differentiation with respect to time, and differentiation with respect to the independent variable itself. Derivatives produced by modulation of the independent variable have the advantage that they are independent of scanning speed, and a narrow bandwidth detection system can be used to minimize background noise. The basis of the method, which can be used to obtain first and higher derivatives, has been considered in connexion with mass spectrometry by Beynon, Clough and Williams.(1)

The method can be applied to a spectrophotometer by modulation of the wavelength incident on the detector, either by vibration of one of the slits(2) or by oscillation of a beam-deflecting mirror within the monochromator. A modification of the former method, which allows a minimum of interference with an existing instrument and the minimum of additional equipment, is described below. Moreover, since no movement of the slit itself is involved, there need be no interference with the normal slit programme of the spectrophotometer.

If a transparent plate *P* is placed in the optical path of a spectrometer as shown in Fig. 1, the effective position of the slit *S* will be dependent on the angle between the plane of the slit and the plate. Modulation of the wavelength can therefore be accomplished by oscillation of the plate about a vertical axis. The effective displacement of the slit is given by $\Delta s = t\Delta\psi(n - 1)/n$ where the plate, of thickness t and refractive index n, is rotated through a small angle n.

An oscillating-plate differentiator of the above type has been used with a type S.4 infra-red monochromator (by Grubb, Parsons and Co. Ltd.). A double-beam instrument was used, operated single-beam with the amplifier tuned to

12½ c/s. A sodium chloride plate enabled derivatives to be obtained over the wavelength range 2–15 μ. Any defocusing effect at shorter wavelengths, due to change in the effective length of the optical path, was minimized with a plate thickness of 1·0 mm. The plate was suspended vertically in the slit assembly by attachment to the centre of a 4 mm ball-bearing race, a rocker-arm being attached to the top of the race. Oscillation was effected by an eccentric wheel, driven by a 3000 rev/min synchronous motor (type FC.34/0 by Evershed and Vignoles Ltd.) through a 4 to 1 reduction gearing. The complete unit could be attached to the slit housing in a matter of minutes, but when in position it did not prevent normal recording with the spectrophotometer.

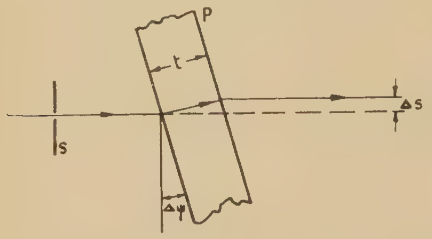

Fig. 1. Slit displacement by transparent plate

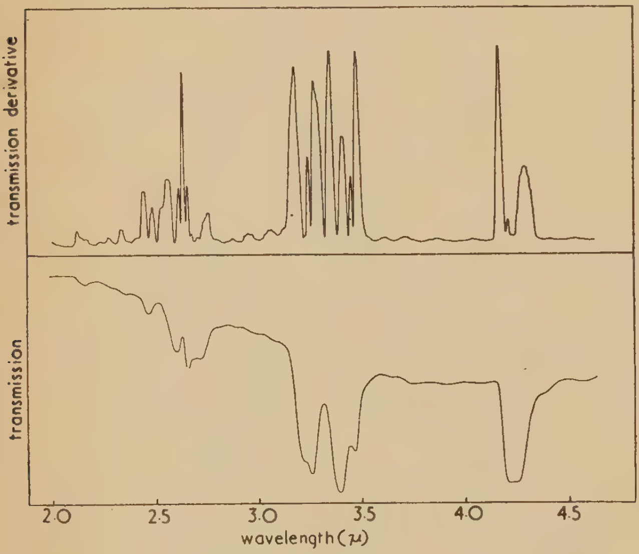

Fig. 2. Derivative spectrum obtained with plate thickness 1·0 mm, angular oscillation 3°

With the type S.4 monochromator and a sodium chloride prism, it can be shown that an angular oscillation of 3° (plate thickness 1·0 mm) results in a modulation amplitude of approximately 0·005 μ at 3 μ. Part of a derivative spectrum obtained using these conditions is shown in Fig. 2, the lower (normal) spectrum containing bands due to water, polystyrene and carbon dioxide. All peaks in the derivative spectrum are positive since the amplifier was not phase sensitive. Slight loss in resolution in the 2·5 μ region was caused by recorder inertia.

In some applications of derivative spectra, particularly for quantitative work, the function $d(\log I)/d\lambda$ may be of greater value than the original function $I = f(\lambda)$. Unfortunately, when derivatives are obtained by modulation of the independent variable, the original function $I = f(\lambda)$ cannot be transformed before differentiation. However, the function $d(\log I)/d\lambda$ could be obtained in the following manner. If the radiation was chopped sinusoidally with a frequency f and modulated by the plate with the same frequency, it can be shown that the signal outputs corresponding to frequencies f and $2f$ would be $I = f(\lambda)$ and $dI/d\lambda$ respectively. These could then be separated by harmonic synchronous rectification,⁽³⁾ the ratio giving the required function

$$\frac{1}{I}\left(\frac{dI}{d\lambda}\right) = \frac{d(\log I)}{d\lambda}$$

However, it would not be possible to do this in the case of the second derivative, since the relationship between the functions is not as simple as for the first derivative.

As mentioned previously, a beam-deflecting mirror within the monochromator could also be used for modulation of the wavelength incident on the detector. The angular oscillation required by the mirror would be considerably less than that necessary for the plate, and might be effected by an electrostriction device, the mirror oscillation and synchronous signal rectification being driven by the same source. Moreover, an oscillator-driven device would allow continuous variation of the modulation amplitude, and this would be of particular value with prism-dispersion spectrophotometers since the dispersion varies with wavelength. Differentiation by the modulation method could readily be combined with the Walsh double-pass system,⁽⁴⁾ simply by replacing the chopper which modulates the second-pass radiation by an oscillating mirror.

The methods described above can also be applied to curve- (or meniscus-) following devices, and the first or higher derivatives of any empirical curve could be obtained directly by using a curve follower of this type.

REFERENCES

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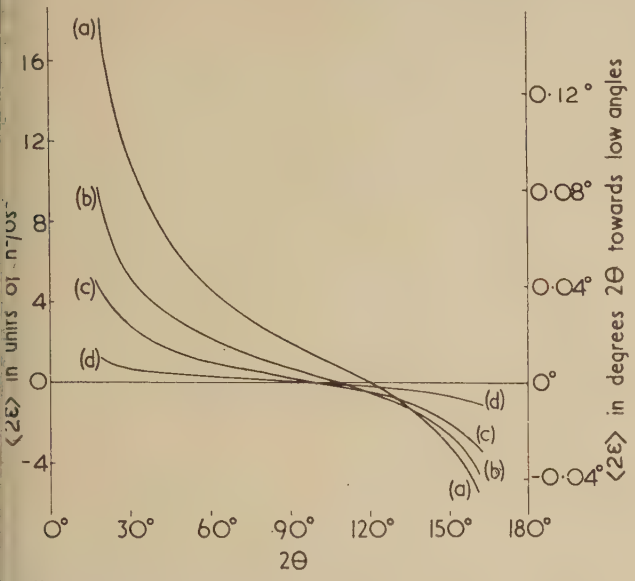
(2) French, C. S., and Church, A. B. *Annual Report of Carnegie Institution of Washington*, p. 162 (1954–5).
(3) Oberley, J. J. *Rev. Sci. Instrum.*, **24**, p. 125 (1953).
(4) Walsh, A. *J. Opt. Soc. Amer.*, **42**, p. 94 (1952).

Correspondence

Counter diffractometer—the effect of vertical divergence on the displacement and breadth of powder diffraction lines

In my paper, published on pp. 355–63 of the September 1957 issue of this *Journal*, Figs. 7, 8 and 9 give the displacements of the centre of gravity of diffraction lines under various experimental conditions. These diagrams have been misinterpreted on several occasions because of the ambiguous manner in which the ordinate scales are labelled. The observed shift of centre of gravity is $\langle 2\epsilon \rangle$ in degrees 2θ, that is, twice the value plotted in the diagrams, which are labelled $\langle \epsilon \rangle$ in degrees 2θ. The values plotted have been misinterpreted as the observed shifts in 2θ, as such diagrams usually show this quantity. In order to remove this risk of confusion it has been suggested by Dr. W. Parrish that all angular quantities connected with the diffractometer be referred to the scale which normally appears directly on the strument, namely, observed values of 2θ. One of the agrams referred to above (Fig. 8) has been relabelled to mply with this convention, and is reproduced below.



Effect on centre of gravity of inserting two sets of Soller slits: (*a*) no slits; (*b*) two sets, $q = 2$; (*c*) two sets, $q = 4/3$; (*d*) two sets, $q = 2/3$. The ordinates on the right give the displacement of centre of gravity for $2h = 1$ cm, $s = 17$ cm

Two small errors which escaped proof correction may also e mentioned. These are: Fig. 5, replace the lower Q_1 (*c*) by $_2$ (*a*), and Fig. 9, transpose the lower (*a*) and (*c*).

iriamu Jones Laboratory,
Jniversity College, Cardiff

E. R. Pike
[14 July, 1958]

Gas circulating pump for enclosed systems

eferring to the note *A simple centrifugal circulating pump*, by M. Benarie, I. Amariglio and M. Mokady, published on . 70 of the February issue of this *Journal*, we wish to state that a similar arrangement has been used for several years in our laboratories for circulating gas in totally enclosed systems.

A solution is circulated in a piece of apparatus by means of a pump of the type described by the above authors. Gas is entrained by the solution as it passes the intake *a* (see figure). Separation of the two phases takes place in bulb *b*. The gas flow depends on the manometric lift. A rotor speed of 1000 rev/min in a chamber of 60 mm diameter gives a lift of 250 mm and a gas flow of 20 l./h. Testing chambers for corrosion, electrolysis, biological measurements, etc., can be placed in the solution line as well as in the gas line.

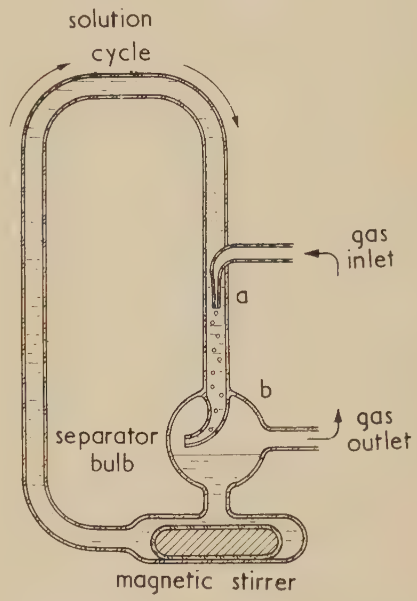


Diagram of gas circulating pump in an enclosed system

Bundesantsalt für Materialprüfung,
Berlin-Dahlem,
Germany.

H.-J. Pagel
W. Schwarz
W. Simon
[11 July, 1958]

NOTES AND NEWS

New instruments, materials and tools

he Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved roducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

alve voltmeter. Winston Electronics Ltd., Shepperton, Middlesex.

he Winston valve voltmeter measures d.c. potentials in five anges from 5 to 1500 V and a.c. potentials in four ranges om 5 to 150 V. A valuable feature is that the circuit is nsulated from earth so that a d.c. voltage between ±450 V earth may be superimposed on any voltage being measured. he a.c. probe uses silicon junction diodes and has an input npedance of 5 MΩ shunted by 5 pF; the capacity of the ther terminal to earth is about 200 pF. An accuracy of 2% n d.c. measurements and 3% on a.c. measurements is laimed, and zero drift is stated to be 1% of full-scale in twelve hours. The meter scale is 5 in. long and has an anti-parallax mirror. An unusual feature is that on d.c. ranges the instrument may be used with either left-hand side, end or centre zero.

Electric furnaces. Royce Electric Furnaces Ltd., Sir Richard's Bridge, Walton-on-Thames, Surrey.

This firm supply a wide variety of electric furnaces made to order. They have made them for operation at temperatures ranging from 150 to 2500° C. In size they range from a few cubic inches to installations of continuous heating furnaces over sixty feet long. Furnaces are supplied with fully automatic temperature control, expansion thermostat, and other devices to suit individual requirements.

Amongst their very varied individualistic machines are the following:

(i) a 50 kW air heater, the function of which is to raise large quantities of air up to 500° C; similar units can be supplied with ratings of 250 kW and higher, with the necessary control gear and blower;

(ii) a continuous pusher-type high temperature kiln for firing ceramics and cerrometals at temperatures up to 1450° C, where units of 30 ft length are in operation, firing in an atmosphere of nitrogen;

(iii) a high temperature atmosphere furnace designed for use with argon gas at temperatures up to 1350° C with a counter-balanced gas-tight hood fitting over the loaded furnace, and locating in a water-seal in the furnace base;

(iv) a box-type furnace for small-scale production or laboratory use supplied with a bench mount or floor stand as required.

Zone melting apparatus. Research Specialities Co., 2005 Garrard Boulevard, Richmond, California, U.S.A.

This consists of a carriage for heaters which is driven at controlled and adjustable speeds along a track of two parallel rails. The heaters, themselves, are not provided, as the user may use either standard heaters or ones made to his own specification. The forms of the motion are

(*a*) slow speed in either direction at from 0·36 to 9·0 in./h, and rapid return in the other direction at 15, 25, or 35 in./min;

(*b*) slow sweep in both directions;

(*c*) rapid travel in either direction, for set-up purposes.

It is claimed that the device provides the necessary mechanical apparatus for linear motion of heaters or samples and can be used in a variety of ways for zone refining, zone levelling, and crystal pulling.

Heating ovens and incubators. A. Gallenkamp and Co. Ltd., Sun Street, London, E.C.2.

The British Standards Institution have made a statement of the standards required in the best drying ovens which they refer to as B.S. 2648.* It includes such things as temperature setting, temperature control and measurement, working space, and ventilation rate. It is stated by this firm that their new ovens comply with this standard. They are employing a new hydraulic thermostat which is designed to meet especially exacting requirements for accurate temperature control, together with automatic compensation for changes in ambient temperature.

The device consists of a sensing bulb connected by a capillary tube to bellows in the control head. These operate a snap-action micro-switch in the heater circuit. The snap-action prevents arcing and gives a contact life exceeding 300000 operations, so that the thermostat setting is not upset by contact wear and there is negligible interference with television and radio. Extra sensitivity is achieved by a small auxiliary heater wound around the capillary tube in the control space and connected in series with the main heaters. The auxiliary heater shortens the cycle of operation, and this limits temperature fluctuation and overshoot. Automatic compensation for changes in control-head temperature (which is the best practical approximation to ambient temperature) is ingeniously achieved by a separate bellows system.

The ovens are available in three sizes, the internal heigh ranging from 14 to 24 in., width from 12 to 20 in., and dept from 12 to 20 in.; they are with or without mechanic convection.

The temperature range is up to 200° C reached from ambien within 65 min. Temperature variation between the midd and any other point of the working space does not excee ±2·5° C and fluctuation at any one point is within 0·25° C The thermostat scale plate on the control panel gives reading in °C. The interiors, shelves and internal fittings are of high grade stainless steel. The exteriors are finished with gre duotone enamel. The notably even distribution of tem perature is achieved by large area heaters and careful therma insulation, which also keeps down running costs.

The incubators are identical in appearance with the oven except for the addition of an internal toughened-glass doo and concealed controls. They are stated to operate betwee ambient temperature and 70° C with a maximum variation a 37° C of ±1° C and maximum fluctuation of 0·1° C.

Optical wedges. Light Filters Ltd., 1–4 Lambeth High Stree London, S.E.1.

A wide range of optical wedges of the cast gelatine type ar available in a variety of sizes and types. Neutral wedges ar made either with material of low scatter or with a scatterin material closely resembling a photographic emulsion. Thes wedges have a substantially uniform absorption betwee 4600 Å and 6400 Å.

Colour wedges can be supplied in yellow, magenta and cyan, and these are normally supplied in sets of three which together, give an almost neutral tint of maximum density 3·0

Wedges are normally supplied on glass, uncemented and bound with a cover glass. Certain types of wedge can, ho ever, be supplied on a cellulose acetate base if required.

Continuous wedges can be supplied either as straigh wedges, in which the optical density increases linearly along the length of the wedge, or as annular wedges, in which the density increases linearly with rotation of the wedge. The linearity of straight wedges is usually somewhat better than that of annular wedges. Step wedges are available to customer's requirements.

Binocular magnifier. Wray (Optical Works) Ltd., Ashgrov Road, Bromley, Kent.

This instrument is specially suitable for the manipulation and working of very small parts. It is particularly favoure by watchmakers, toolmakers working on small and intricate dies, and similar workers, because it enables them to concentrate on a magnified image for long periods withou eye-strain, and at the same time allows plenty of room t manipulate their work.

The magnification is ten times linear and there is a clearance of 7 in. between the object glasses and the focused image At one setting a clear circular field of 22 mm can be examined. No special illumination system is required; the ordinar room lighting produces a brilliant image. The image is see the right way round and the right way up so that no confusion occurs in manipulating objects in the field. Adjustment is provided for different eye separations and each eyepiece focuses separately, thus making allowance for any differences between the two eyes of the observer.

The ×10 binocular magnifier is fitted to current models of the electron microscope (by Metropolitan-Vickers Electrical Co. Ltd.) and can be used with earlier models.

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* Copies of B.S. 2648:1955 may be obtained from the British Standards Institution, 2 Park Street, London, W.1. Price 3*s*.

New books

lectronic components handbook. Vol. 2. Edited by K. HENNEY and C. WALSH. (New York: McGraw-Hill Book Co. Inc.; London: McGraw-Hill Publishing Co. Ltd., 1958.) Pp. 357. Price 97*s*.

ike Volume I, which was reviewed in this *Journal* in ovember 1957, the contents of this handbook are concerned ith American military electronic equipment. Specifications id type numbers are therefore only strictly relevant to such omponents. However, there is much valuable information f a general nature in each section concerned with the haracteristics of the several components and with the eneral requirements which must be met in their manufacture nd use for maximum reliability: these sections well repay udy by users and manufacturers alike.

The components dealt with are power sources and con-erters, fuses and circuit breakers, electrical indicating instru-ients, printed wiring boards, solder and fluxes, choppers, lowers, drive motors and filters, r.f. transmission lines and aveguides.

A. J. MADDOCK

eflex klystrons. By J. J. HAMILTON. (London: Chapman and Hall Ltd., 1958.) Pp. xi + 260. Price 45*s*.

he author ranges from the fundamental mathematical nalysis of the electron dynamics of reflex klystrons to ractical details of the many and varied processes of their nanufacture and finally examines future trends in this field. n such a comprehensive undertaking brevity is inevitable nd occasionally results in slight obscurity but on the whole he author has been very successful in achieving his declared bject "to integrate and present the principal facets of nowledge of these oscillators." References at the end of ach chapter are numerous but sometimes include what ppear to be reports not available to the general reader.

G. L. HUNT

dictionary of named effects and laws in chemistry, physics and mathematics. By D. W. G. BALLENTYNE and L. E. Q. WALKER. (London: Chapman and Hall Ltd., 1958.) Pp. vi + 205. Price 30*s*.

The intention of the authors of this book is to enable a eader to find out, with a minimum of interruption to his tudies, what *X*'s effect or law is; in this they have succeeded within a limited scope. There are some 800 entries ranging rom Abbe's sign condition to the Zeeman effect, each of 50–100 words or so, and "pruned free from historical and ther background matter."

It is not clear what terminology has been used in regard o such words as "law," "equation" and "theorem." Thus we find "Bragg equation" for what is often known as "Bragg's law" among crystallographers, and "Joule's law" for the heating effect of a current, often referred to as the "Joule effect." The latter, however, is stated to be the "mechanical change in length when subjected to a magnetic field" which might be regarded as the opposite of the Villari effect. Cross references would be a useful addition.

Although some of the well-known numbers like Reynolds and Mach's are included there are many other which might be considered for future editions, for example, those bearing the names of Graetz, Grashof, Lewis, Margoulis, Nusselt, Peclet, Prandtl, Schmidt and Stantion.

In an appendix, definitions of 18 units, mostly electrical are given; why these few should have been selected is not at all clear.

It is a pity that so promising a book should have to be sold at such a high price.

H. R. LANG

Chambers's technical dictionary. Revised ed. (Edinbrugh: W. and R. Chambers Ltd., 1958.) Pp. 1028. Price 35*s*.

This useful dictionary containing some 60 000 terms was first published in 1940 and has been revised and reissued with supplements several times since then. The present (third) edition has been "heavily revised" and the "greatly enlarged supplement contains a wealth of new terms relating to the latest advances in science and technology." English-speaking scientists, engineers and indeed "all those who wish to understand what they have to say to each other" have, for the last 18 years, been indebted to the compilers of this valuable work and will continue to be so long as it is kept up to date in these days of rapid progress. Tables in the field of chemistry, geology, botany and zoology are included. A helpful feature is the inclusion of an observation after each term showing to which branch of science or engineering the term relates; although some might disagree with the classifications given, especially as the boundaries between subjects are so very uncertain. The noble attempt to distinguish trade names accurately when so many have almost become, if not have actually reached, the status of generic terms, will be appreciated by all technical writers and editors. In such a work it is not difficult to find points with which one might disagree, and as the editors explained in their preface, many of these are matters of opinion on which experts differ. Rightly they have chosen to use the forms and definitions preferred by those who are actively engaged in the practice and teaching of their respective subjects rather than any more academic and pedantic definitions.

The productions and format is adequate for the comparatively low price of such a valuable work, but there might be a sale for a de luxe edition perhaps in two or more volumes.

H. R. LANG

Notes and comments

Symposium on current developments in the production of high vacua

The Institute of Physics is arranging a one-day symposium, entitled Current developments in the production of high vacua, to take place in London on 17 April, 1959. There will be three sessions:

(*a*) Chemical and ionic pumping in kinetic vacuum systems.
(*b*) Problems in the production of high vacua in large equipment.
(*c*) Analysis of residual gases in kinetic vacuum systems.

Each of the first two sessions will be opened by invited speakers, and offers of short contributions, especially for the third session, will be considered by the Organizing Committee if outlines are submitted forthwith.

The symposium is intended mainly for persons working with high vacua. Abstracts (but not preprints) will be circulated before the symposium, the proceedings of which will not be published in full.

All communications regarding the symposium should be sent to the Secretary, The Institute of Physics, 47 Belgrave Square, London, S.W.1.

Conference on some aspects of magnetism

The Institute of Physics announces that it is arranging a conference on some aspects of magnetism to take place in

Sheffield from 22–24 September, 1959. The subjects to be covered by the conference are:

(*a*) Fundamental theories to ferro-, ferri- and antiferromagnetism, including magnetic structure.

(*b*) Theories of technical magnetization processes, including hysteresis, coercivity, anisotropy and directional effects.

(*c*) Theoretical and experimental studies of domain phenomena in bulk materials and thin films.

(*d*) Experimental and theoretical studies of antiferromagnetism in metals and non-metals.

Each session will be opened by an invited speaker and offers of other contributions should be submitted to the Conference Secretary at The Institute of Physics, 47 Belgrave Square, London, S.W.1, before 31 January next. The conference is intended mainly for persons working in the field. Abstracts (but not preprints) will be circulated before the conference, the proceedings of which will not be published in full.

Further particulars will be available in due course from the Secretary, The Institute of Physics at the above address.

Convention on thermonuclear processes

The Institution of Electrical Engineers has arranged a convention on thermonuclear processes to be held in London on the 29 and 30 April, 1959. Details of the programme has not yet been finalized, but the probable range of topics to be covered is as follows: basic physics of thermonuclear processes; prototype British thermonuclear experiments—Zeta 1, Sceptre 111 and the linear pinch; constructional features of Zeta 1; design problems in future Zeta type systems; possibilities of direct conversion from nuclear to electrical energy.

Reviews of related work in the U.S.A. and the U.S.S.R. will also be included in the programme. Further details can be obtained from The Secretary, The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

International convention and exhibition on transistors

The Institution of Electrical Engineers has arranged an international convention on transistors and associated semiconductor devices, to be held at Earls Court, London, 21–27 May, 1959, which, it is hoped, will be the most comprehensive ever held on the subject. Associated with the convention will be an international scientific exhibition. Further details can be obtained from the Secretary, The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Health Physics

The latest addition to the several new periodicals, associated with applied physics, which have recently appeared is entitled *Health Physics* and is the official journal of the Health Physics Society, founded at the University of Michigan in 1956. The Society met during 1957 in Pittsburgh and a selection of the papers then presented are to be published in the first few issues of the new periodical. Health physics is defined as "a study and practice dealing with any and all factors relating to damage from ionizing radiation and t prevention of such damage." In addition to specialist pape survey sheets and notes and new items are promised.

The subscription rate is £6 ($17) p.a. and the publisher Pergamon Press Ltd. Members of the Health Physics Socie subscribe at special rates.

Lapis

A new monthly journal entitled *Lapis* was first publish in October 1958. The first issue list patents (Governme and industrial) available for manufacture under licenc inventors seeking manufacturers; inventions for which pr visional patents are being taken out and manufacturers sought agents seeking agencies, and companies seeking agents.

The journal is published by Kenneth Mason Publication 1 Old Burlington Street, London, W.1. Subscription pric is £10 10*s*. p.a.

Register of British manufacturers

The 1959 edition of the F.B.I. register of British manu facturers provides a comprehensive guide to a substantia cross-section of British industry, listing the products an services of over 7500 firms who are members of the Federatio of British Industries, under more than 5400 alphabetica headings. The headings used are: products and service addresses, trade associations, brands and trade names, trad marks. In addition there are language glossaries in French German and Spanish.

The register is published by Kelly's Directories Ltd., an Iliffe and Sons Ltd., Dorset House, Stamford Street, Londo S.E.1. The price is 42*s*.

British Journal of Applied Physics

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S-band ferrite isolator for use with a linear accelerator. From C. S. Gaskell and D. Walsh.

Radiofrequency method for the measurement of conductive liquid saturation in a porous medium. From R. W. Snell.

Centripetal air-pump operated electromagnetically. From B. Popper and M. Reiner.

NOTES AND NEWS

Notes and comments

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Nuclear spin pulse apparatus

By K. Luszczynski, B.Sc., and J. G. Powles, Ph.D., D.ès.Sc., Physics Department, Queen Mary College, University of London

[*Paper first received* 17 *June, and in final form* 22 *September*, 1958]

A detailed description including circuits and operating instructions, is given for the construction of a nuclear spin pulse apparatus which will measure nuclear spin-lattice relaxation times from 500 μs upwards and nuclear spin-spin relaxation times from 20 μs upwards over the temperature range −180° C to 220° C with an accuracy of better than ±5%. An Appendix lists where all published circuit diagrams and technical data suitable for spin echo apparatus may be found.

e paper gives a detailed description of a simple nuclear gnetic resonance pulse apparatus developed in this oratory. Although suitable apparatus has been described ewhere,(1–10) these accounts generally discuss only certain ts of the equipment and do not give complete circuits from ich the apparatus could be readily constructed (see pendix). We feel that our equipment is rather simpler d cheaper to construct than most of the ones that have en described. We discuss also a number of technical ficulties which can now be easily resolved. Transient clear magnetic resonance signals are discussed in the erature(1, 5, 11–14) but in order to introduce the terminology d notation we give a brief description of the principles of experiments.

A sample containing magnetic nuclei, e.g. protons, is placed a polarizing field H_0 and subjected to short pulses of ernating magnetic field $2H_1 \cos \omega_L t$, at right angles to H_0, ere $\omega_L = \gamma H_0$ is the angular Larmor precession frequency the nuclei in H_0. Provided H_1 is greater than the inhomo-eity of H_0 over the sample the macroscopic nuclear gnetization is nutated through an angle θ after a time t_w ere $t_w \ll T_2$ and

$$\theta = \gamma H_1 t_w \tag{1}$$

is the gyromagnetic ratio of the nucleus and t_w is the lse width. A pulse corresponding to a nutation of θ is erred to as "θ-pulse." Appropriate choice of pulses, t_w's, d pulse separations τ's, gives rise to various nuclear signals luced by the sample in the receiving coil.

From such nuclear signals one can in principle determine transverse, T_2, and longitudinal, T_1, relaxation times. The nal may also depend on the self-diffusion constant D, the clear magnetic shielding (or chemical shift δ), and on the direct spin-spin coupling J in certain materials(1, 15, 16) so at these parameters can also be measured. The effects served may also depend on a number of other phenomena, ch as the exchange of nuclei between molecules, and so nstitute an important method of investigating materials.

THE APPARATUS

The equipment described here was developed to generate accurately controlled sequence of r.f. pulses, of variable dth t_w, power H_1, and separation τ, and to detect and splay the small nuclear signals. It can be divided into ur parts, as shown on Fig. 1:

(*a*) generation of a controlled sequence of radio frequency lses, (*b*) reception of the nuclear signal, (*c*) amplification d display of the signal, and (*d*) auxiliary units.

The individual parts are discussed below in varying detail, pending on their complexity and importance.

(*a*) *Generation of a controlled sequence of r.f. pulses.* Some typical pulse sequences required are:

- (i) two pulses of pulse width t_w and $2t_w$ respectively with a variable time separation τ, e.g. $t_w = 20$ μs, and τ varying from 1 ms to 100 ms. H_1 for protons is then 3 G for a 90°-pulse which requires about 20 V r.f. on the usual coil.
- (ii) a train of pulses with the first pulse t_w and all subsequent pulses $2t_w$ with separation τ between the first and second pulse and a separation 2τ between the following pulses. τ should again be variable.

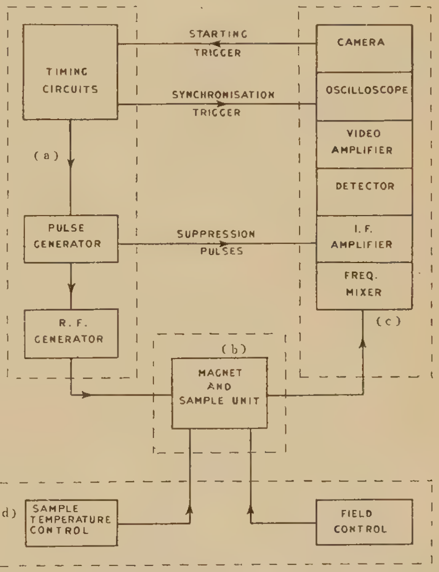

Fig. 1. Block diagram of the complete apparatus

The method adopted is summarized in Figs. 2 and 3. A selected sequence of accurately timed triggers was fed into a double-channel square pulse generator which controlled the output of a radio frequency generator. Trigger pulses, derived from the basic interval generator (Airmec type 702 plus dekatron scaling units giving 0·03 to 30 000 pulses/s) were fed to an electronic gate which was normally closed. An initiating trigger, obtained from oscilloscope camera shutter contacts, opened the electronic gate, the output of which was injected into a double-channel pulse generator, and a 2^n scaler. The latter was set to generate a trigger, after a selected number of triggers had passed which closed the electronic gate thus limiting the number of triggers contained in the sequence to a preselected value.

The two independent pulse generators were preceded by units which we call stop-pass circuits. By appropriate choice of switch settings (see Fig. 4) these could: (*a*) pass the first pulse only, and stop all following pulses, or (*b*) pass odd

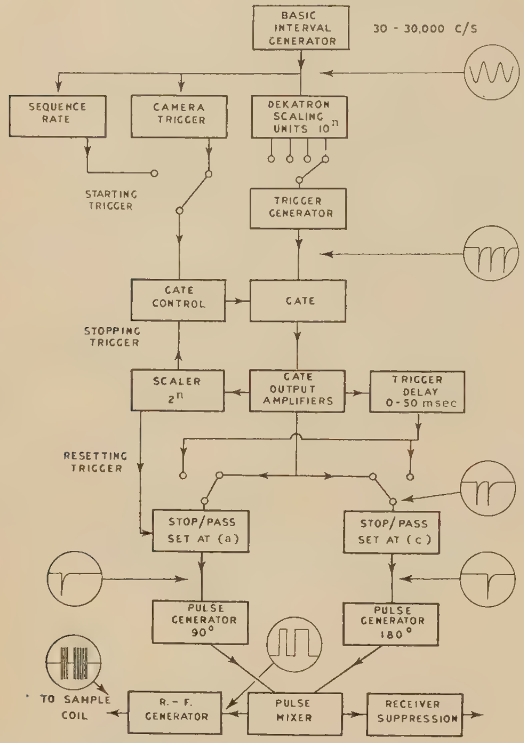
BASIC INTERVAL GENERATOR
30 - 30,000 c/s
SEQUENCE RATE
CAMERA TRIGGER
DEKATRON SCALING UNITS 10ⁿ
STARTING TRIGGER
TRIGGER GENERATOR
GATE CONTROL
GATE
STOPPING TRIGGER
SCALER 2ⁿ
GATE OUTPUT AMPLIFIERS
TRIGGER DELAY 0-50 msec
RESETTING TRIGGER
STOP/PASS SET AT (a)
STOP/PASS SET AT (c)
PULSE GENERATOR 90°
PULSE GENERATOR 180°
TO SAMPLE COIL
R.-F. GENERATOR
PULSE MIXER
RECEIVER SUPPRESSION

Fig. 2. Block diagram of timing and pulse generating units

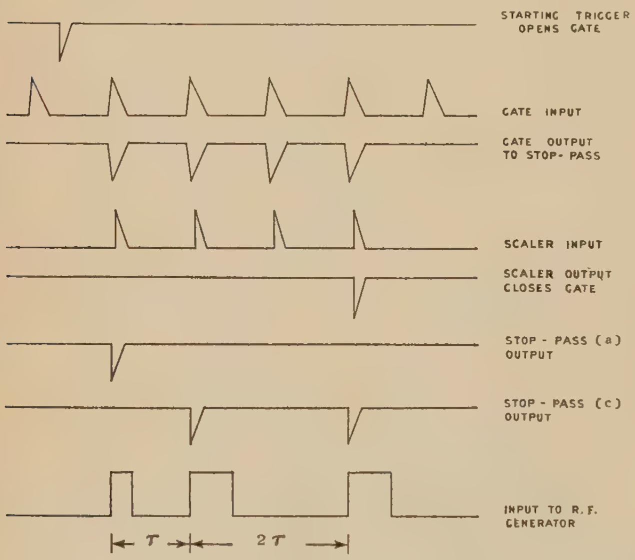
STARTING TRIGGER OPENS GATE
GATE INPUT
GATE OUTPUT TO STOP-PASS
SCALER INPUT
SCALER OUTPUT CLOSES GATE
STOP - PASS (a) OUTPUT
STOP - PASS (c) OUTPUT
INPUT TO R.F. GENERATOR
τ
2τ

Fig. 3. Waveform in timing circuits for generation of 90°, τ, 180°, 2τ, 180° sequence. Drawing is not to scale

pulses only, or (*c*) pass even pulses only. Thus for (*b*) and (*c*) the pulse separation is doubled. Monostable multivibrators were used to produce rectangular positive pulses continuously variable in width from 3 to 200 μs with about 1 μs (90% − 10%) edges and of amplitude 120 V, on a −120 V base line. The generators were stable and insensitive to pulse repetition frequency (PRF), i.e. to τ, over whole range used.

The pulses which were generated independently in the t channels of which only one is shown in Fig. 4 were co bined in a double cathode-follower (pulse mixer in Figs and 4). The level to which these gating pulses rose dur their positive excursion was clamped to ground potent *via* a diode V_{14}, to ensure that this level remained const irrespective of PRF and pulse width.

The circuit of the pulsed radio frequency generator is giv in Fig. 4. Both the oscillator and the power stage are gat Gating of the oscillator eliminates radio frequency leaka between pulses, but naturally the pulses so produced phase-incoherent. Pulsing the r.f. power stage is a desirable because it allows peak power dissipation by t valve greatly in excess of its rated value, and also becau noise voltage injected into the sample coil is considerab reduced. With this generator r.f. pulses of 30 V peak a about 2 μs edges (90% − 10%) were obtained across t sample coil. Pulse widths between 20 and 100 μs w generally used. A single valve r.f. power oscillator can al be used,(1, 3, 6) an advantage is that it can be made ve compact and situated in the immediate vicinity of the samp coil and so be more effectively screened. We are investigati a circuit of this type.

For a study of the nuclear signal phase relations a sour of phase-coherent r.f. pulses is necessary.(1, 10) In this ca the oscillator must run continuously and only the amplifyi stages are gated. Complete elimination of leakage may b however, quite difficult. Phase-coherence could be obtain by making the pulse oscillator start up on a small sign obtained from a continuously running low power oscillato

In addition to the principal units already described furth units required (Fig. 2) include a trigger-delay unit, giving pulse separation independent of basic interval τ; a frequen standard, for accurate determination of τ and oscillosco time-base calibrations; a suppressor, which is a pulse inver ing and elongating amplifier, whose output renders th receiver i.f. amplifier insensitive during the pulses; a finally a display rate control, which is a low frequenc (0·1–100 pulses/s) trigger generator determining the rate at which a sequence is produced and which is used main for alinement.

The principal feature of the pulse-timing circuits is the freedom from PRF effects in the range 0 to 30 000 pulses/ The sequence selected may be composed of an indefinitel large number of pulses. We have obtained up to 200 echoe in one sequence. The initiation of a sequence and resettin of the circuits is completely automatic, except for the camer shutter. The starting trigger is arranged to occur at a suitabl point in the basic interval otherwise the first pulse of th sequence may be adversely affected. Variation of puls separation τ can also be made automatic by using a rotar switch, with multiple contacts which changes the puls separation in steps after each pulse sequence.(17) Puls sequence generators using commercial pulse equipment a components tend to be expensive since the sequences require differ substantially from those used in other fields.

(*b*) *Reception of the nuclear signal.* The receiving arrange ment is determined mainly by the nuclear resonant frequency Frequencies ranging from 2 kc/s to 45 Mc/s have been em ployed in transient signal experiments.(2, 7, 10, 18, 19) In general the amount of information contained in the nuclea signal increases with the resonant frequency, i.e. with field and so does the signal intensity.

We have used a permanent magnet (Mullard type PM 36)

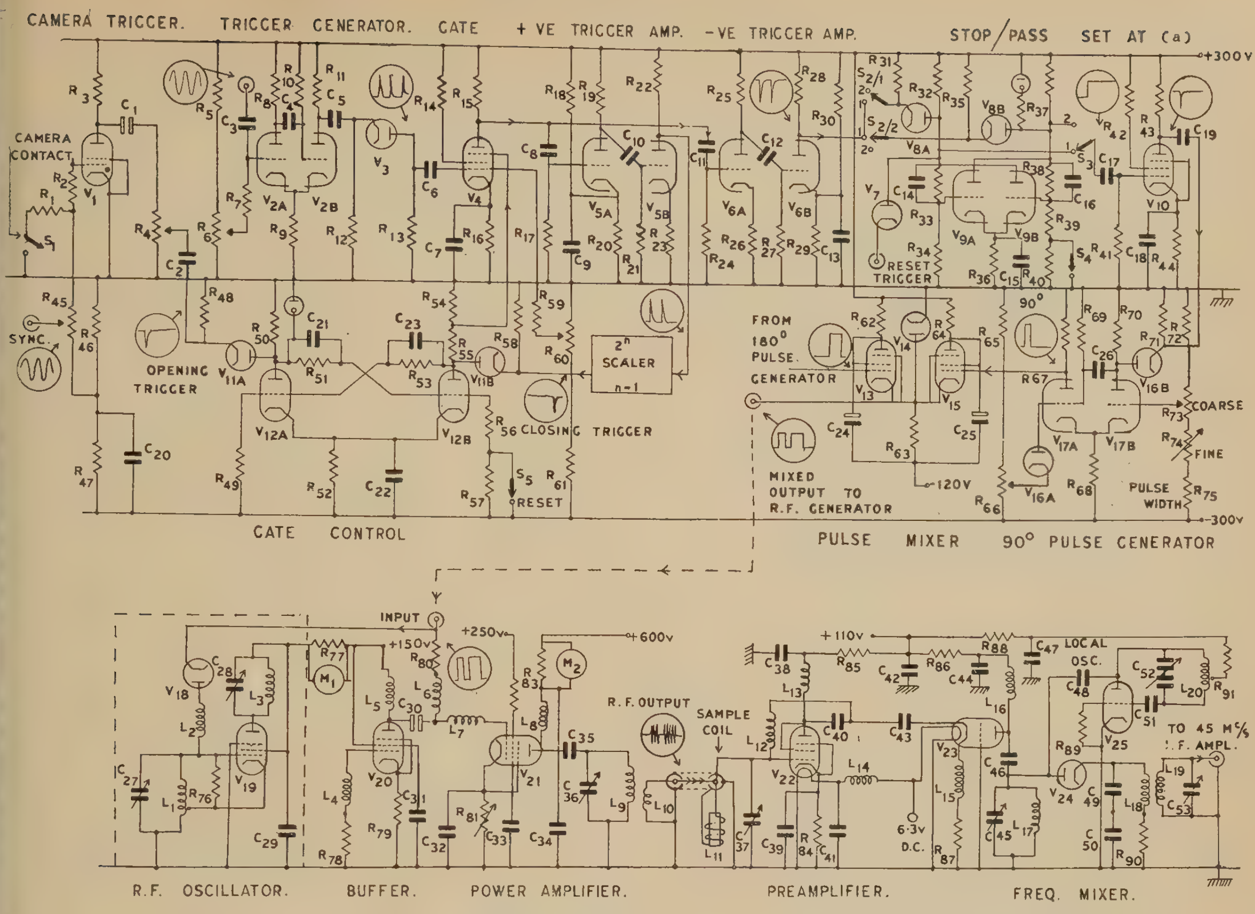
CAMERA TRIGGER.
TRIGGER GENERATOR.
GATE
+VE TRIGGER AMP.
-VE TRIGGER AMP.
STOP/PASS
SET AT (a)
+300 V
CAMERA CONTACT
S_1
$S_{2/1}$
$S_{2/2}$
S_3
S_4
RESET TRIGGER
SYNC.
OPENING TRIGGER
V_{11A}
V_{11B}
V_{12A}
V_{12B}
56 CLOSING TRIGGER
2^n SCALER
n-1
S_5
RESET
GATE CONTROL
FROM 180° PULSE GENERATOR
MIXED OUTPUT TO R.F. GENERATOR
-120 V
90°
COARSE
FINE
PULSE WIDTH
-300 V
PULSE MIXER
90° PULSE GENERATOR
INPUT
+150 V
+250 V
+600 V
M_1
M_2
R.F. OUTPUT
SAMPLE COIL
+110 V
LOCAL OSC.
TO 45 Mc/s I.F. AMPL.
6·3 V D.C.
R.F. OSCILLATOR.
BUFFER.
POWER AMPLIFIER.
PREAMPLIFIER.
FREQ. MIXER.

Fig. 4. Circuit diagram of the basic apparatus

The maximum number of pulses in the sequence is determined by the scaler setting, i.e. n. Switch $S_{2/1}$ determines whether single (1) or multiple (2) triggers are admitted to the pulse generators. Switch S_3 selects odd (1) or even (2) triggers. Pulses generated independently in the two channels are mixed in cathode follower V_{13}–V_{15}. Only one of two stop-pass and pulse-generator circuits are shown. The other is identical and feeds the grid of V_{13}. Either pulse generator can produce pulses of variable length corresponding to 0 to 540°. They are normally adjusted to provide 90° or 180° r.f. pulses according to the sequence in use. Heater supplies are at: +300 V, 0 V, −120 V and −300 V.

All resistors are ½ W, carbon, 10%, unless otherwise stated. All capacitors are paper, not less than 300 V, unless otherwise stated.

= 39 kΩ
= 1 kΩ
= 2 MΩ
= 100 Ω, 10 W, w.w. pot.
= 500 kΩ, 1 W
= 100 kΩ, 3 W
= 22 kΩ
= 5·6 kΩ
= 5·6 kΩ
= 6 MΩ
5·6 kΩ
= 10 kΩ
= 10 kΩ
= 15 kΩ
= 22 kΩ
= 470 Ω
= 47 kΩ
= 150 kΩ, 1 W
= 22 kΩ
= 10 kΩ
= 100 kΩ
= 15 kΩ
= 1·2 kΩ
= 100 kΩ
= 22 kΩ
= 470 Ω
= 47 kΩ
= 18 kΩ
= 10 kΩ
= 150 kΩ, 1 W
= 47 kΩ
= 22 kΩ, 1 W
= 220 kΩ
= 100 kΩ
= 47 kΩ
= 10 kΩ
= 22 kΩ
= 220 kΩ
= 100 kΩ

R_{40} = 100 kΩ
R_{41} = 47 kΩ
R_{42} = 20 kΩ
R_{43} = 4·7 kΩ
R_{44} = 6·8 kΩ
R_{45} = 1 MΩ, 2 W, carbon pot.
R_{46} = 100 kΩ, 1 W
R_{47} = 330 kΩ, 1 W
R_{48} = 22 kΩ
R_{49} = 100 kΩ
R_{50} = 22 kΩ, 1 W
R_{51} = 220 kΩ
R_{52} = 10 kΩ
R_{53} = 220 kΩ
R_{54} = 3·9 kΩ
R_{55} = 18 kΩ, 1 W
R_{56} = 100 kΩ
R_{57} = 100 kΩ
R_{58} = 22 kΩ
R_{59} = 10 kΩ
R_{60} = 100 kΩ, 2 W, carbon pot.
R_{61} = 470 kΩ, 1 W
R_{62} = 2 kΩ, 5 W, w.w.
R_{63} = 5 kΩ, 5 W, w.w.
R_{64} = 2 kΩ, 5 W, w.w.
R_{65} = 100 kΩ, 10 W, w.w.
R_{66} = 50 kΩ, 3 W, w.w. pot.
R_{67} = 5·6 kΩ, 1 W, h.s.
R_{68} = 5 kΩ, 5 W, w.w.
R_{69} = 5 MΩ, 1 W, h.s.
R_{70} = 5·6 kΩ, 1 W, h.s.
R_{71} = 47 kΩ
R_{72} = 120 kΩ, 10 W, w.w.
R_{73} = 20 kΩ, 3 W, w.w. pot.
R_{74} = 500 Ω, 3 W, w.w. pot.
R_{75} = 10 kΩ, 1 W, h.s.
R_{76} = 47 kΩ
R_{77} = meter shunt
R_{78} = 2·7 kΩ

R_{79} = 62 Ω
R_{80} = 2·2 kΩ
R_{81} = 300 Ω, 3 W, w.w. pot.
R_{82} = 47 kΩ, 1 W
R_{83} = meter shunt
R_{84} = 150 kΩ
R_{85} = 2 kΩ
R_{86} = 2 kΩ
R_{87} = 100 Ω
R_{88} = 1 kΩ
R_{89} = 10 kΩ
R_{90} = 2 kΩ, 1 W, h.s.
R_{91} = 1 kΩ

C_1 = 2 μF
C_2 = 100 pF
C_3 = 0·01 μF
C_4 = 0·01 μF
C_5 = 50 pF
C_6 = 0·001 μF
C_7 = 0·01 μF
C_8 = 100 pF
C_9 = 500 pF
C_{10} = 0·1 μF
C_{11} = 0·01 μF
C_{12} = 100 pF
C_{13} = 500 pF
C_{14} = 50 pF
C_{15} = 0·01 μF
C_{16} = 50 pF
C_{17} = 50 pF
C_{18} = 0·001 μF
C_{19} = 0·01 μF
C_{20} = 0·1 μF
C_{21} = 50 pF
C_{22} = 0·01 μF
C_{23} = 50 pF
C_{24} = 16 μF el., 600 V
C_{25} = 16 μF el., 600 V

C_{26} = 20 pF
C_{27} = 50 pF. air. var.
C_{28} = 50 pF air. var.
C_{29} = 0·1 μF
C_{30} = 100 pF mica
C_{31} = 0·01 μF
C_{32} = 0·01 μF
C_{33} = 0·01 μF
C_{34} = 0·001 μF mica
C_{35} = 0·001 μF mica
C_{36} = 150 pF air. var.
C_{37} = 100 pF
C_{38} = 0·01 μF
C_{39} = 0·01 μF
C_{40} = 0·001 μF mica
C_{41} = 100 pF cer.
C_{42} = 0·01 μF
C_{43} = 0·01 μF mica
C_{44} = 0·01 μF
C_{45} = 50 pF air. var.
C_{46} = 0·001 μF mica
C_{47} = 0·01 μF
C_{48} = 3 pF cer.
C_{49} = 25 pF air. var.
C_{50} = 0·001 μF
C_{51} = 10 pF cer.
C_{52} = 250 pF mica tr.

L_1 ≃ 2 μH
L_2 = 20 μH r.f.c.
L_3 = 2 μH
L_4 = 2 mH r.f.c.
L_5 = 2 mH r.f.c.
L_6 = 20 μH r.f.c.
L_7 = 1 μH
L_8 = 2 mH r.f.c.
L_9 ≃ 2 μH
L_{10} ≃ 0·5 μH
L_{11} = 0·5 μH

L_{12} ≃ 20 μH
L_{13} = 30 μH
L_{14} = 13 μH r.f.c.
L_{15} = 1 mH r.f.c.
L_{16} = 1 mH r.f.c.
L_{17} ≃ 2 μH
L_{18} = 0·6 μH
L_{19} ≃ 0·1 μH
L_{20} = 1 μH

V_1 = EN91 camera trigger
V_2 = ECC82 trigger generator
V_3 = EA50 rectifier
V_4 = 6F33 gate
V_5 = ECC82 positive trigger amplifier
V_6 = ECC81 negative trigger amplifier
V_7 = ½EB91 blocking diode
V_8 = EB91 blocking diode
V_9 = ECC82 stop-pass
V_{10} = EF91 stop-pass output
V_{11} = EB91 blocking diode
V_{12} = ECC82 gate control
V_{13} = EL821 pulse mixer
V_{14} = EB91 clamping diode
V_{15} = EL821 pulse mixer
V_{16} = EB91 clamping diode
V_{17} = ECC82 pulse generator (90°)
V_{18} = ½EB91 blocking diode
V_{19} = 6SK7 r.f. oscillator
V_{20} = 6V6 buffer amplifier
V_{21} = 807 power amplifier
V_{22} = EF95 preamplifier
V_{23} = EC91 preamplifier
V_{24} = EA50 rectifier
V_{25} = EC91 local oscillator

M_1 = M_2 = 5 mA meter

having 4 in. pole faces, 17/16 in. gap, and a field of 5030 G. For this field the proton signal is at 21·5 Mc/s. The field homogeneity, with current shims, was better than 100 mG/cm at the optimum position. Two pairs of coils on the pole pieces gave field shifts of up to ±50 G and ±5 G respectively.

For the purpose of temperature stabilization and screening the magnet was lagged with 1½ in. expanded polystyrene sheet and enclosed in a copper box. Magnet temperature fluctuations were less than 1° C per day. A removable aluminium kinematic stand, placed on the magnet yoke, supported the sample assembly, matching unit, preamplifier, batteries, etc. External electrical interference proved troublesome and limited the sensitivity of the equipment in spite of elaborate screening and earthing. Locating the whole of the equipment in a screened room or "cage" would be desirable.

The circuit arrangement for reception of the nuclear signal is shown in Fig. 4. A sample coil, used both for generation of H_1 and reception of the nuclear signal was in the first tuned stage of a low-noise (cascode) preamplifier. The circuit as shown in Fig. 4 was used for small samples ($\sim$0·01 cm^3), i.e. for weak signals. For larger coils and samples the preamplifier was unnecessary and was replaced by a cathode follower which improved the matching of the sample coil to transmitter and receiver. The nuclear signal, for protons at 21·5 Mc/s, was amplified about 50 times and heterodyned with the output of a 66·5 Mc/s local oscillator, and the 45 Mc/s output was fed to a band-pass amplifier. A diode was used for the frequency mixer to avoid signal to noise deterioration likely to occur with frequency converting valves, and also because fast recovery from saturation by the pulses, from which this circuit is not protected, could be achieved with this simple system.

Effects of saturation and paralysis of the initial amplifying stages though difficult to avoid entirely can be made negligible in a number of ways. Suppression of h.t. supply to the initial amplifiers(16) is effective but complicated by the long time-constants associated with such circuits. An orthogonal coil arrangement used with a bridge can provide up to 120 dB attentuation, of which 80 dB is due to geometry alone.(20–23) The bridge becomes less effective as the pulse width decreases. The orthogonal coil arrangement has the additional advantage that the transmitter and the receiver coil can be individually matched and adjusted, and that the noise injected into the sample coil is reduced. A very short recovery time is possible with extremely long bias-supply time constants, but for large pulse widths and high PRF this can result in cumulative reduction of gain thus limiting the flexibility of the equipment. The method adopted here, with a single coil system, was to let the initial stages saturate, but to reduce their recovery time to a minimum by keeping the bias time-constants very short ($\sim$2 μs). Recovery-time in the later stages of amplification, in which pentodes were used, was further reduced by means of g_3-suppression. An overall recovery-time of less than 10 μs has been obtained.

The peak voltage Vp of the nuclear signal is given by(11)

$$V_p \simeq 4\pi\frac{(I+1)}{3I}\cdot\frac{1}{(a^2+b^2)^{\frac{1}{2}}}\,\frac{n\mu^2}{kT}\,\omega_L H_0 NQV \times 10^{-8}\ \text{V}$$

where a, b, Q, N are the diameter, length, Q, and number of coil turns respectively. I is the nuclear spin, n is the number of nuclei per cm^3, k is Boltzmann's constant, μ is the magnetic moment of the nucleus and V the volume of the sample. Sample size is limited by the H_0 inhomogeneity which can be tolerated. Sample volumes ranged from 0·01 to 1 cm^3.

Thus the signal is proportional to the Q of the coil. M over the noise decreases with increasing Q. (In the abse of external interference the measured noise level at the sam coil was between 0·1 and 0·5 μV.) However, the bandwi needed for minimum tolerable distortion, limits the maxim Q for the sample coil which can be used. A further limitat is that with our single coil arrangement it was the coil-r and not the paralysis of the receiving chain that limited obs vation of signals immediately following the intense r.f. pul Coils having Q's of not more than 40 gave a signal-to-no ratio of about 10 with 0·01 cm^3 water samples. This ra could be further improved by reduction of the external in ference possibly by using a single valve oscillator as alrea suggested.

(c) *Amplification and display of the nuclear signal.* T nuclear signal is amplified at minimum permissible ban width, until noise introduced by the succeeding stages amplification becomes negligible. Radio frequency amp fication of the signal at a convenient intermediate frequen and bandwidth is continued to a fairly high level, usually about 10 V peak to ensure linear detection down to low leve using a 45 Mc/s band-pass (4 Mc/s at ±1 dB) amplifier s (Pye type RU 196). A linear detector (½6AL5 with 0·5 *RC* time-constant) was d.c. coupled to a linear video oscil scope amplifier (d.c. – 2 Mc/s), and displayed (Solartr type CD 513). The signals were recorded on Ilford 5G green-sensitive film. The Schackman 35 mm camera shut contacts triggered the timing circuits. A long persisten screen was used (Solartron type CD 523) for visual obse tion of the nuclear signals.

The quality of photographs consisting of multiple expos would be improved and visual measurements facilitated z-modulation. Accuracy of measurement of transient nuc signals, such as echoes, may be increased by using a "bo car" integrator.(4, 24)

(d) *Auxiliary equipment.* It is necessary to be able control the main field H_0 and the physical state of the samp A very simple cryostat was used giving the temperature ra from −180° C to +220° C with an accuracy of ±1° C abo room temperature, and ±3° C at low temperatures. Te perature stabilization is less important than in steady sta measurements. All power supplies were stabilized. Drift H_0-field was small and could be easily corrected with th field-bias coils. Electronic stabilization of the field is al possible.(25) The H_0 field inhomogeneity could be varied b means of the current shims. The whole apparatus, with th exception of commercial units, specifically mentioned, wa constructed in this laboratory.

EXPERIMENTAL PROCEDURE

This consists of preliminary adjustments, final alinemen of apparatus and measurement of relaxation times. See als Refs. (5) and (9). Only final alinement is described.

(a) *Alinement*

After several hours warming up, a single pulse is generate and t_w increased from zero until the nuclear decay signa following the pulses, reaches its first maximum. The field H is then shifted to maximize this decay and this gives a approximate 90° pulse. Another pulse is then generated b the second channel, and t_w increased from zero until th first signal minimum is obtained. To reduce this decay t zero it may be necessary to adjust the field-bias. This puls is an approximate 180° pulse. The two pulses are then dis played together, with 90° pulse leading, which gives a stron o, provided $\tau \lesssim T_2$, and the first pulse is adjusted for ximum echo amplitude. The apparatus needs no further ustment except for a small, slow drift of H_0 which is easily rected with the field-bias coils, using a 180° pulse as an icator. The pulse sequence selected is dictated by the gnitude and type of relaxation time to be measured. The rval between sequences, Θ, should be kept greater than .

T_1-measurement

'or T_1-measurement the pulse sequence is 180° followed τ r by 90°.(12) The decay $h(\tau)$, after the second pulse varies h τ according to the relation:

$$h(\tau) = h_{max}[1 - 2\exp(-\tau/T_1)]$$

$|h(\tau)|$ goes from h_{max} for $\tau = 0$ through zero, at = $\tau_{null}/ln2$ to h_{max} at $\tau = \infty$. Fig. 5 is a multiple exposure otograph showing this behaviour of $|h(\tau)|$. $ln(1 - h(\tau)/h_{max}$ inst τ gives a straight line with slope $1/T_1$. This method nimizes any error due to inaccuracies in t_w, and it also valid in cases where $t_w \simeq T_2$. Determination of T_1 by asuring τ_{null} is rapid but less accurate. T_1 can be thus asured conveniently from 0·5 ms to many seconds. T_1 also be deduced from a stimulated echo,(1, 7) but this is y suitable when the effect of self-diffusion is small.

T_2-measurement

Method $C(T_2)$. Short T_2's between 20 and 500 μs were asured(26) from the Bloch decay after a 90° pulse. The per limit is set by H_0 inhomogeneity and the lower by t_w l coil ringing.

Method $A(T_2)$.(12) Intermediate values of T_2, between ms and 300 ms, were measured by applying pairs of 90°, °-pulses, and observing echo amplitude $e(2\tau)$ as a function τ (Fig. 6). This method may be severely limited by self-usion effects. The highest value of T_2 that can be measured his way will therefore depend on the H_0-field gradient over sample and the self-diffusion constant D. In the presence spin-spin coupling the echo amplitudes may be modulated l the form of modulation depends on the pulse sequence ployed.

Method $B(T_2)$. T_2's from 0·5 ms to many seconds were ally measured using a sequence consisting of 90°, τ, °, 2τ, 180°, 2τ, 180, . . . pulses, which give echoes at 2τ, . . . determined mainly by T_2 (Fig. 7). The remaining ct of self-diffusion, if any, can be removed by varying basic pulse separation, and extrapolating to $\tau = 0$, at ich self-diffusion effects disappear. The echo pattern ained with this method is also affected by spin-spin ipling.

Results

Some typical photographs are shown in Figs. 5 to 8. re examples will be found in Ref. (26). The time scale s in most cases provided by the r.f. pulses whose separation simply related to the accurately known PRF. If this was practicable timing pulses were derived from a 100 kc/s stal.

Errors

Erroneous results will be obtained whenever any of the ameters, f_{osc}, H_1, τ or t_w, in particular, deviate from their rect values.(5)

Method $B(T_2)$ is particularly sensitive to any deviations cause the errors accumulate as the sequence progresses. r example, a 10% error in t_w (180°) reduces a 7·2 ms time nstant decay to less than 6·2 ms with erratic echo pattern when $\tau = 1{\cdot}25$ ms. It is therefore important that the gating pulse generators are free from jitter and PRF effects, to within ±1%, over the range of PRF's used. Our pulses were accurate to at least ½%. The accumulation of error due to faulty 180° pulses in the 90°, 180°, 180°, . . . , $B(T_2)$, method can be considerably reduced by using phase coherent pulses and arranging the 90° pulse to be 90° out of r.f. phase relative to the 180° pulses.(27) We have, however, found it possible to use the $B(T_2)$ method in favourable circumstances with more than one hundred 180° pulses without error in T_2 due to this cause. The effect of intermittent fluctuations in τ is small and none was observed. The stability of the basic interval generator was better than 0·2%/h.

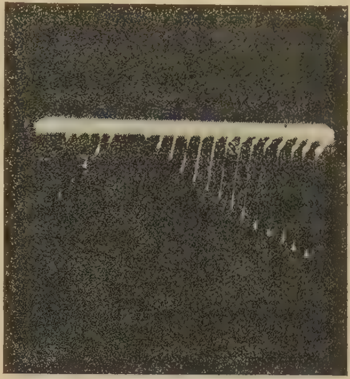

Fig. 5. T_1-measurement

A multiple (21) exposure photograph showing $h(\tau)$ for glycerol at 17° C. τ is increased successively by 1 ms from 10 ms to 30 ms. $h(\tau = 10)/h(\infty) = 0{\cdot}272$, $h(\tau = 16{\cdot}3) = 0$, $T_1 =$ 23 ms. Total sweep about 24 ms, time origin not shown at left.

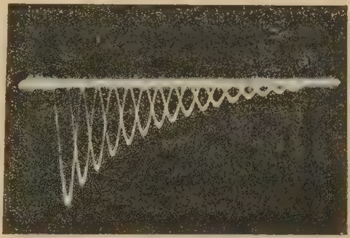

Fig. 6. T_2-measurement by method *A*

A multiple (16) exposure photograph showing echo decays for glycerol at 17° C. $T_2 = 11{\cdot}8 \pm 0{\cdot}5$ ms. 2τ is increased successively by 2 ms from 10 to 40 ms. Total sweep 43 ms, time origin at left not shown.

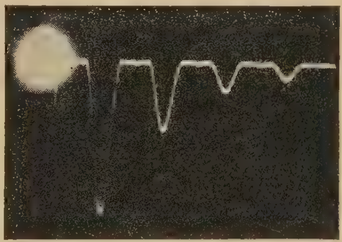

Fig. 7. T_2-measurement by method *B*

A single exposure photograph showing echo decay for glycerol at 17° C. $T_2 \simeq 11$ ms. Part of the tail following the 90° pulse is seen near the origin. Echoes occur at $2\tau (= 7{\cdot}8$ ms), 4τ, 6τ and 8τ. Total sweep 39 ms. Field homogeneity ($\simeq 0{\cdot}1$ G) is the same as in Fig. 6. Normally a larger number of echoes is used for measuring T_2.

The frequency and magnitude of H_1 are, to some extent, affected by the potential to which the gating pulse rises. This level should therefore be clamped to a reference voltage. Precautions have to be taken to minimize oscillator frequency fluctuations or drift, a shift of 5 in 10^5 in f_{osc} is detectable with a 180° pulse. Deliberate misalinement by changing f_{osc} or H_0 by known amounts after setting up a known pulse is a convenient method of measuring the magnitude of H_1.(13) It should be recalled that H_1 is only half the actual field amplitude on the sample.

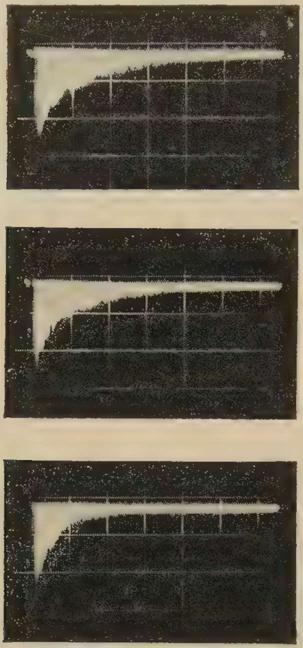

Fig. 8. Effect of self-diffusion, on method B (T_2), in iso-butyl-bromide at 20° C

Top photograph: $\tau = 6{\cdot}62$ ms, middle $\tau = 8{\cdot}0$ ms, bottom $\tau = 10$ ms. Hence assuming that the diffusion effect is proportional to τ^2, $T_2 \simeq 1{\cdot}0$ s is arrived at. (Method A (T_2) yields $T_2 \simeq 50$ ms.) Also self diffusion constant $D \simeq 3 \times 10^{-4}\ \mathrm{cm^2\,s^{-1}}$. Field gradient 0·45 G/cm, assumed to be linear. Total length of sweep $=3{\cdot}65$ s. The photographs are single exposures and each contains about two hundred echoes.

A further source of error is inhomogeneity of H_1. However, if the method of alinement suggested in this paper is used an automatic compensation is introduced which means that only very serious inhomogeneity of H_1 would be troublesome in the measurement of T_1 and T_2. With serious H_1 inhomogeneity a 180°, τ, 90° pulse sequence gives rise to a small split-echo at 2τ. In echo modulation experiments(15) the effect is more important and special precautions have to be taken to reduce H_1 inhomogeneity. Relative nuclear signal amplitude measurements were generally accurate to better than 1%. Signal distortion by the amplifying system was negligible. The oscilloscope graticule was not used in time measurement.

Measurement of the signal immediately following an intense r.f. pulse requires special precautions, as in the case of T_1-measurements, from $|h(\tau)|$, following the second pulse. The decay of the intense pulse is extended by the coil-ring, and interferes with the nuclear signal destructively when $\tau < \tau_{null}$ and constructively when $\tau > \tau_{null}$. This effect gives a false indication of the peak amplitude, as shown in Fig. 9. The error was avoided by measuring at a fixed time after the pulse to avoid the region of interference. Photogra such as Fig. 5, are usually in error due to this effect anc have not used them for measuring T_1.

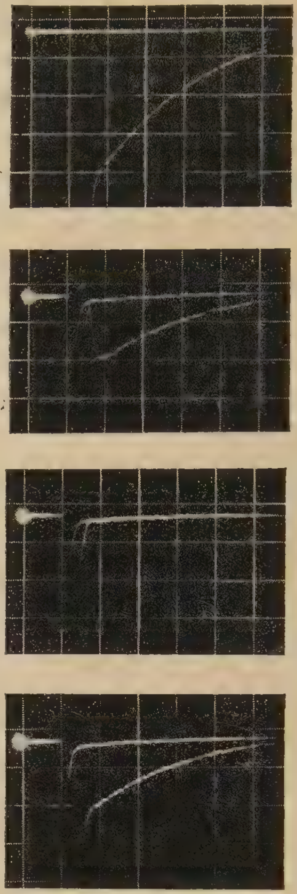

Fig. 9. Nuclear signal [$h(\tau)$] following a 90° pulse i 180°, τ, 90° sequence in polyisobutylene at 19° C

From top to bottom the photographs show: $h(\infty)$, $h(6{\cdot}62$ ms), $h(16{\cdot}7$ ms) $\doteq 0$ and $h(40{\cdot}0$ ms). Interference of the nuclear signal with the r.f. pulse is constructive for $\tau > \tau_{null}(=16{\cdot}7$ s and destructive for $\tau < \tau_{null}$. Amplitude of the signal must therefore be measured at, say, 70 μs from the origin. Sweep $=35\ \mu$s/cm division. The decay of signal with time is mainly due to T_2 ($\simeq 90\ \mu s$). Upper signal in the lower three photographs is the coil ring after the 180° pulse.

CONCLUSION

The simple pulse timing apparatus described may be us to generate all pulse sequences so far employed for nucle magnetic resonance experiments and many others. T flexibility is high because the apparatus is composed individual units, which can be interconnected in a variety ways.

T_1 can be measured, with overall accuracy of better th 5%, from 0·5 ms to many seconds. T_2 can be measured better than 5%, from 20 μs to several seconds. The upp limit of T_2-measurements, complicated by the self-diffusio effect, can be further extended by extrapolation with som loss in accuracy. There is some prospect for measuring ver short T_2's, e.g. in solids using the pulse technique, by method devised to reduce the sample coil "ring."(18, 23)

There is no upper limit on either T_1 or T_2-measurement but since the time interval Θ between pulse sequences shoul at least five times T_1, measurement of long relaxation nes is unavoidably tedious.

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APPENDIX

Circuit diagrams and details of certain components of nuclear spin pulse apparatus will be found in the literature as follows (numbering is as in References):

(1) Circuit diagram of a single stage gated oscillator; also a phase coherent r.f. pulse generator (30 Mc/s). (2) Generation of timing triggers and r.f. pulses (30 Mc/s). (3) Circuit for single stage pulsed oscillator generating H_1 up to 100 G (30 Mc/s). (4) Circuit of a box-car integrator for transient nuclear signals (3–15 Mc/s). (5) Description of apparatus only (27·5 Mc/s). (6) Single stage r.f. generator (30 Mc/s) and frequency converter (150–17 Mc/s). (7) Signal strength and sample coil discussed, no circuits (16·5 Mc/s). (8) Circuit for a trigger timer and a single stage r.f. generator (17 Mc/s). (9) Apparatus composed of (U.S.) commercial units described. Circuit of gated oscillator and r.f. power amplifier (30 Mc/s). (10) Pulse apparatus for frequencies between 15 and 42 Mc/s. Circuits of pulse mixer, oscilloscope trigger selector, staircase generator and i.f. amplifier (25·5 Mc/s). (18) Description of pulse apparatus at 2 kc/s (in earth's field). (20) Describes an orthogonal coil arrangement (7·76 Mc/s). (21) A simple orthogonal coil arrangement (10 Mc/s). (23) Circuit diagram of a ringing-circuit r.f. generator for 0·3 μs, $H_1 = 1$ G, pulses (17·4 Mc/s). (27) Transmitter gate and doubler (15·30 Mc/s). Device for electronically operated r.f. phase shift.

Wide range recording anemometer*

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[*Paper first received* 16 *May, and in final form* 12 *August*, 1958]

The anemometer described uses optical linkages to measure wind speeds from 2 to 100 miles/h and wind direction to within ±2°. The output is in the form of pulse-modulated signals suitable for counting directly or for recording on magnetic tape.

ıe anemometer described was developed for use in an vestigation of mechanical vibrations caused by the action wind on the conductors of overhead transmission lines. ıese vibrations occur at wind speeds down to 1 mile/h. To rther the investigation, records of both the speed and rection of the winds were required. Although there was no terest in wind speeds above 25 miles/h, the instrument had be capable of withstanding the highest wind speeds and sts to be expected on exposed sites. The instrument had so to produce information in a form suitable for recording magnetic tape.

Existing instruments were found to be either (i) adequately bust, but insensitive to low wind speeds, or (ii) adequately sensitive to low winds, but too delicate for permanent exposure outdoors. The windmill type of instrument appeared to offer the best possibilities of development, and an existing design† was, therefore, adopted for this purpose.

The existing instrument was found to fail at wind speeds below 5 miles/h, because of mechanical friction in the speed-measuring mechanism. The design was modified by replacing the existing mechanism by one using optical linkages. A direction-measuring system incorporating optical linkages was also developed.

In this way the total internal friction was reduced effectively to the mechanical friction in the bearings, and by suitable design and construction it was found possible to achieve the required performance at low wind speeds.

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* Based on E.R.A. Report O/T21.

† Wax, M. P. *An Experimental Study of Wind Structure* (British Electrical and Allied Industries Research Association Report Ref. C/T114, 1956).

DESIGN

Basis of speed measurement. As shown in Fig. 1, a light windmill mounted on free-running bearings turns a cylindrical rotor *C* carrying three concave mirrors. Light from a small electric lamp travels up a cylindrical light guide, is reflected by the mirrors, travels back down the light guide, and is detected by a phototransistor. This system produces three pulses for each revolution of the windmill. After being appropriately shaped, these pulses are suitable for counting directly or for recording on magnetic tape.

Basis of direction measurement. Movement of the tail fin by the wind moves a small mirror *A* in the body of the anemometer to a position determined by the direction of the tail fin. Beneath this mirror a rotating disk, driven by a synchronous motor, carries on its upper surface a lamp and phototransistor unit arranged so that, when it passes directly below mirror *A*, a light is reflected on to the phototransistor to produce an electrical pulse once per revolution of the disk. On the underside of the disk is fastened another mirror *B* which passes over a stationary lamp and phototransistor unit *C* and so produces a reference pulse once per revolution of the disk. The time interval between the two pulses gives a measure of the angle between the mirror *A* and the internal reference and hence gives the wind direction, as described later.

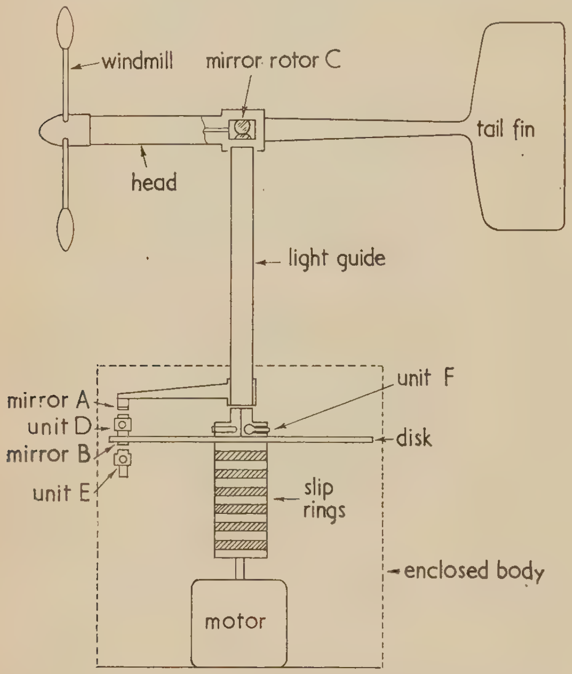

Fig. 1. Diagram to illustrate the mechanism of the anemometer

Construction. In order to achieve a lightweight structure of adequate strength, the head of the anemometer is made of aluminium alloy, while the fin is made of laminated balsa wood and aluminium alloy sheet built up with cold-setting resin adhesive. The head is supported by axial and radial thrust ball races and carries the Perspex light guide and the mirror *A*.

The windmill consists of four blades of laminated ba wood mounted on an aluminium alloy hub. The blades a smooth, circular paddles built up with a cold-setting res adhesive, which is also used to fasten them to the hub.

The lower end of the light guide is located just above t top of the speed measuring lamp and phototransistor unit which is mounted at the centre of the rotating disk. Althou this unit rotates with the disk, the rotation has no effect the speed signal provided that the light guide and the unit are properly alined. Any misalinement causes unev illumination of the phototransistor and can give rise spurious signals when the windmill is stationary. Howev slight misalinement can be remedied by slightly rougheni the ends of the light guide to produce more diffuse illuminati

One of the two lamp and phototransistor units used f measuring direction (*D*) is also mounted on the disk a connexions to the units *F* and *D* are taken through silve graphite brushes running on silver slip rings. The system turned by a geared synchronous motor at 30 rev/min.

The body is enclosed by an aluminium alloy shell with base plate threaded for mounting on a 2 in. diameter ste pole. Electrical connexions to the anemometer are ma through two waterproof plugs and sockets mounted on t shell.

The major constructional problem associated with t lamp and phototransistor units was found to arise from t fact that the available phototransistors were sensitive to he as well as to light. It was therefore necessary to design t unit to give maximum light transfer with minimum he transfer. Coupled with this was the requirement that physical size of the mirror had to be small to give adequa resolution in the measurement of direction. It was foun that a satisfactory compromise could be reached by: (i) coa ing the insides of the units with white paint in order to redu light absorption; and (ii) mounting convex lenses over apertures in the units in order to produce convergent lig beams, and so increase the proportions of the total lig intercepted by the mirror and by the aperture over t phototransistor.

Associated circuitry. The output of the speed-measuri phototransistor is first fed to an integrating circuit, the amplified and finally clipped to give pulses suitable for dire recording on magnetic tape or for operating a counter.

The output from the instrument or from the magnetic ta is normally read by means of an electronic counting circui which gates and counts a 100 c/s reference signal over period occupied by one hundred pulses from the anemomete This process is repetitive so that a direct reading of reciproc mean wind speed, in digital form, is continuously provide The time over which the mean is taken varies, according the wind speed, from 1 to 100 s. If required, the reading ma readily be transformed into analogue form for the productio of speed/time curves.

The two short pulses from the phototransistors in th direction indicating system are arranged to produce a sing gating signal having a duration equal to the time interv between them. The gating signal is applied to a 50 c/s trai of 10 ms pulses derived from the mains, so as to produc groups of pulses separated by 20 ms. As shown in Fig. the wind direction is derived by counting the number whole pulses in a group.

This count is normally carried out by an electronic countin circuit which gives a direct digital indication of the numbe of pulses in a group. This constitutes a measure of th instantaneous direction of the wind at the end of the coun The counting operation is repetitive, so that an indication ind direction is provided which is revised at intervals of two conds. If required, the reading may readily be transformed to analogue form for the production of direction/time irves. The lamps are fed with direct current to avoid the jectionable modulation which occurs when an a.c. source used.

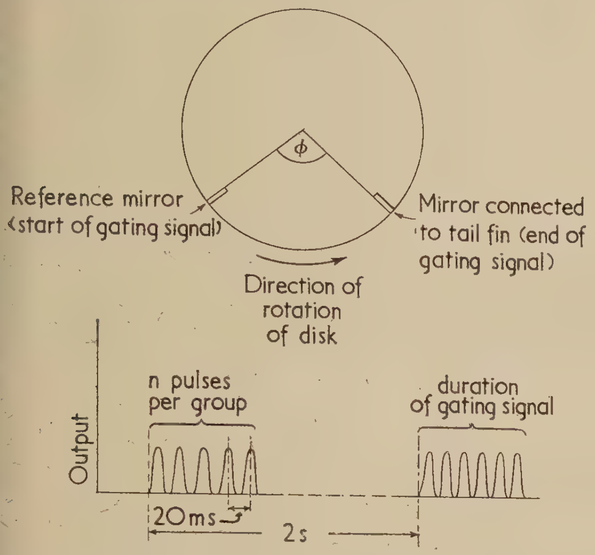
φ
Reference mirror (start of gating signal)
Mirror connected to tail fin (end of gating signal)
Direction of rotation of disk
Output
n pulses per group
duration of gating signal
20ms
2 s

Fig. 2. Principle of the direction measurement

100 pulses per group represent 360° deflexion, therefore 1 pulse per group represents 3·6° deflexion, therefore $\phi = 3\cdot6\,n°$

Adjustment. The lenses are mounted in adjustable housings hich are set by trial to give the maximum output from the hototransistors with the mirrors located directly over the nits. The supply is adjusted until there is just enough light produce an adequate output from the phototransistors ·5 V peak). The supply to the driving motor is also gulated so that the torque is just sufficient to give reliable peration. Under these conditions the heat produced inside e body of the instrument is at a minimum and the resulting mperature rise of the phototransistors is found to be well ithin their maximum rating.

To ensure accurate determination of wind direction the ead of the anemometer is set to horizontal by the aid of a irit level.

APPLICATION

The anemometer is mounted at the top of a 2 in. diameter eel pole supported by stays. The leads run from the instru-ent to a suitable shelter which houses the associated ectronic equipment. When the instrument is set up the irection of zero output from the direction measuring system determined and is subsequently used as a reference.

CALIBRATION

The speed-measuring apparatus was calibrated in a low-rbulence wind tunnel at the National Physical Laboratory. he output was plotted against wind speed for three separate indmills and a typical result is shown in Fig. 3. There were ly slight differences between windmills and these were due slightly different blade setting angles.

The speeds at which the windmill started and stopped were so determined, using a sensitive vane anemometer to easure the wind speed. The anemometer was carefully velled and the lowest speeds at which the tail was able to ving the body into line with the wind were measured.

PERFORMANCE

Fig. 3 shows that there is a linear relationship between wind speed and the output from the anemometer. There is a slight falling off at the low-speed end of the plot and the windmill stops at about 1 mile/h. The actual stopping and starting speeds are dependent on the bearing friction. This in turn depends on the lubricant in the bearings. It was found that both the starting and the stopping speeds were slightly higher after the anemometer had been in a high-speed wind for some time. It was thought that some of the lubricant was flung out of the bearings at these high speeds. A silicone lubricant was used in preference to a mineral oil, because its viscosity was less dependent on temperature.

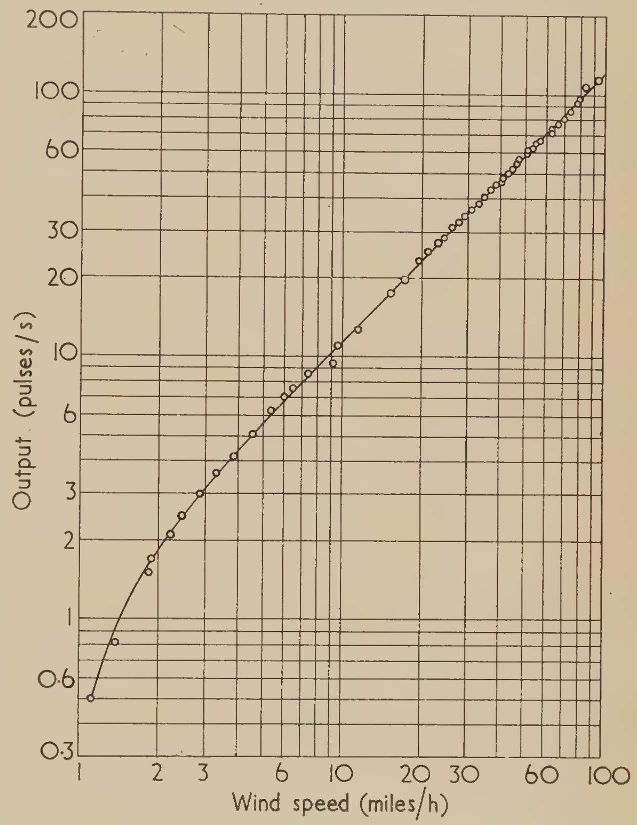

Fig. 3. Relationship between wind speed and output

The starting speed was always slightly higher than the stopping speed and varied from 1 mile/h at the beginning of tests to 1·8 miles/h at the end. The corresponding stopping speeds were 0·8 mile/h and 1·4 miles/h.

The wind speeds at which the body alined itself with the wind were always just too low to be measured on the sensitive vane anemometer, and must therefore have been about 0·5 mile/h. Thus the body was always correctly alined before the windmill started to run.

The speed-measuring system worked well at wind speeds of up to 95 miles/h. There was a slight low-frequency yawing of the body at high speeds, but this should not affect the accuracy of the readings since a yaw of about 20° would be necessary to produce an error of 1%.* Measurements made in the wind tunnel confirm these figures.

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* Ower, E. *The Measurement of Air Flow*, 3rd ed. (London: Chapman and Hall Ltd., 1949).

It was not possible to test the anemometer in a pulsating air stream. The work of Ower indicates that it should overestimate the average speed, but that this error should be small provided that the extremes of speed are not more than about 15% on either side of the mean.

The measurements made in the wind tunnel were subject to blockage and wake errors due to the obstruction caused by placing the anemometer in the tunnel. These amounted to about 4%. The accuracy of the speed-measuring system with the tunnel empty was about 1%, making the overall accuracy about 5% for the whole range of measurements.

The calibration of the direction-indicating system consisted of finding the position of zero output and suitably marking it on the casing of the anemometer. The number of pulses in each group of the output was then counted for several different positions of the tail, and the angular deflexions calculated as shown in Fig. 2. The linear relationship between the number of pulses and the angle was checked by means of a protractor. This relationship was found to be accurate to within ±2°.

CONCLUSIONS

The anemometer will measure wind speeds from 2 100 miles/h and has been calibrated with an accuracy about 5%. It will measure wind direction with an accura of ±2°.

The tail of the anemometer pulls the body into line wi the wind well before the lowest speeds at which the blad start to turn.

The pulse-modulated signals from the speed- and directio measuring mechanisms are suitable for counting directly for recording on magnetic tape.

The anemometer has been working on an exposed site the South Coast for a period of one month and has prov entirely satisfactory.

ACKNOWLEDGEMENTS

The author is indebted to the Director of the Briti Electrical and Allied Industries Research Association f permission to publish this paper. He also wishes to expre his thanks to Dr. G. Mole for his guidance in this work.

Two emission stabilizers for electron-bombardment furnaces

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Stabilization requirements and techniques for electron-bombardment heating are considered, and basic design formulae are presented for a flexible control system applicable to temperature-limited emission furnaces. Power handling capacity, loop stability and speed of response are discussed, and full circuit details of practical stabilization systems for a 250 W and a 6 kW furnace are given. It is concluded that emission stabilization is always beneficial, and sometimes essential, and that emission stabilities of better than 0·5% at powers up to 20 kW are practicable.

The need for metallurgical processing of very refractory and/or reactive metals, coupled with increasingly severe requirements for high-purity melting and refining, has led to the development of furnace techniques in which the melt is free from contamination by either crucible or ambient atmosphere. One of the more recent methods is the electron-bombardment technique, in which the charge to be processed forms the anode of a diode valve, and is bombarded by electrons emitted from a suitable cathode. The technique has been widely used for zone melting, using the "floating-zone" method,(1) and furnaces and processing methods have been described.(2, 3)

Some of the getter-pumping systems which have been devised for the production of uncontaminated high vacua(4) incorporate electron-bombardment furnaces as an essential part of the mechanism. The process produces a continuous gettering action by the controlled melting of a titanium wire, fed continuously on to a bombardment-heated hearth. Other possible applications are in the growth of semiconductor monocrystals, and in certain welding processes.(5)

THE NEED FOR STABILIZATION

Many electron-bombardment devices are inherently unstable unless fed from a very high impedance ("constant current") supply. Instability may arise from the out-gassing of the heated charge: this produces ions which bombard the filament, raising its temperature and causing increased electron emission. The process is cumulative and the system "runs away." A similar instability mode can result from changes of filament work function with vacuum conditions inside th furnace. If there is significant space-change limitation current, instability can also result from ionic annulation the space-charge. These effects can be so severe as to rend manual operation of the furnace impossible.

The discussion of control systems in this paper will b confined to furnaces operated under temperature-limite emission conditions, since this would appear to be the mo important practical case. With space-charge-limited opera tion, current stabilization presents no problems and circu design is conventional and well established. Furthermor since with space-charge-limitation the control parameter the anode-cathode voltage of the furnace, the furnace powe can vary widely and uncontrollably. Under temperature limited conditions, on the other hand, control is effected b variation of the filament power, and, if the anode voltage constant, stabilization of the emission stabilizes the powe input also whilst allowing the latter to be easily varied b adjustment of anode voltage. The electronic design of regulator to control the filament power is made more difficu by the presence of the filament time constant and the non linear filament-power-emission relationship, whilst the filamen power itself has generally to be supplied at an inconvenient low impedance level.

STABILIZATION TECHNIQUES

Whatever the method of filament power control used will usually be convenient to measure the emission curren by passing it through a suitable resistor, the drop acros ich is compared with a reference voltage. The error signal us derived is then amplified and fed to a controller which ries the filament heating power degeneratively.

The control techniques generally available are:

(i) electromechanical (servo-controlled Variac or power rheostat);
(ii) magnetic amplifier or transductor;
(iii) electronic impedance;
(iv) time-modulation (switching) systems.

Of these, method (i) suffers from mechanical complexity d lack of response, though it is extremely flexible and has en used in this application.(6) Method (ii) has many vantages, but for research work is objected to on the ounds that such devices are inflexible and need to be signed for particular load conditions. Method (iii), whilst ceptable at low power levels, involves large valves and avy-duty supplies if powers of more than, say, 30 W are be controlled. There remains method (iv), in which the wer is controlled by rapidly switching the filament on and f, the on-off duty ratio determining the load power. A ven electronic device can control more power when used this way than when used as a simple impedance, and ually needs simpler power supplies. The particular system be described has been used for emission stabilization at ament power levels of from 1 W to 2 kW. The design iteria are straightforward, the system is flexible, and a sponse time of a half-cycle of supply frequency is possible.

THE CAPACITOR-FED SHUNT CONTROLLER(7)

The schematic diagram of Fig. 1 shows the basis of the stem. The filament is fed from a.c. mains *via* a step-down ansformer T, which has a capacitor C in its primary circuit. carries an additional control winding, conveniently biphase, iich feeds thyratrons V_1, V_2. The series capacitor value is

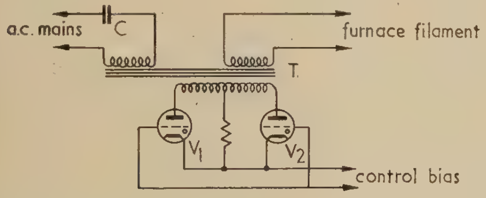


Fig. 1. Schematic diagram of controller circuit

ch that an essentially constant current is supplied to T imary; if neither thyratron is conducting, a defined current fed to the filament. On the other hand, conduction in her thyratron effectively short-circuits the filament which, ıder such conditions, receives virtually no power. The ean power supplied to the filament can be controlled by riation of the firing angle. The adoption of a biphase ntrol circuit, coupled with appropriate biasing arrange-ents, enables "full-cycle" control of the thyratrons to be alized.

The choice of value of series capacitor is arbitrary: it ust have a reactance sufficiently high to ensure the relative nstancy of current which is a necessary feature of the rcuit. An optimum value is in the neighbourhood of $\omega C = 2R'$ where R' is the filament resistance referred to e transformer primary, and the choice of this figure also s the practical advantage that, with a 240 V mains supply standard, 110 V primary transformers can be used. All the design criteria given are established on this basis; the significant parameters are the turns ratios on the transformer, and the power handling capacities of particular thyratrons.

The maximum power to be supplied to the filament can be taken as some two to five times greater than that mean power which gives the appropriate emission. This power is supplied when the thyratrons are fully non-conducting, and the appropriate turns ratio, primary to load secondary, is:

$$N_1 = \sqrt{\left(\frac{V^2}{5 \times P_{max} R_f}\right)} \qquad (1)$$

where V is the a.c. line voltage and R_f the filament resistance. Under maximum power conditions, the limiting thyratron parameter is the maximum instantaneous forward or reverse voltage, whichever is the lower; whilst with both thyratrons fully conducting the average anode current rating is significant. The product $V_{pk} I_{av}$ is thus a figure of merit for a valve used in this circuit, and is related to P_{max} by:

$$P_{max} = 1{\cdot}4 \times V_{pk} I_{av} \qquad (2)$$

If N_2 is the turns ratio half secondary to primary, its value for maximum thyratron utilization is:

$$N_2 = 0{\cdot}6 \sqrt{\left(\frac{V_{pk}}{I_{av} . R'}\right)} (R' = R_f N_1^2) \qquad (3)$$

The minimum power supplied to the filament will be insignificantly small in most cases. Hence the range of filament power will be from substantially zero to P_{max}.

LOOP GAIN AND STABILITY

In any degenerative closed-loop system the effects of disturbing influences on the controlled quantity are reduced by a factor $|1/(1 + \mu\beta)|$ relative to the open-loop case. In typical emission-stabilization problems, uncontrolled changes are such that loop gains of the order of 1000 are necessary to achieve an emission stability of a fraction of 1%. The application of such loop gains necessitates precautions against self-oscillation, particularly if response time is not to be sacrificed. The maximum loop gain which can be applied without instability in a system with three significant time-constants $\tau_1 > \tau_2 > \tau_3$ is:

$$\mu\beta_{max} = \tau_1/\tau_2 \qquad (4)$$

This is a "just stable" criterion and yields a highly-under-damped response. If $\tau_1 > \tau_2 \gg \tau_3$ critical damping occurs if:

$$\mu\beta = \left\{\frac{[1 + (\tau_1/\tau_2)]^2}{[4(\tau_1/\tau_2)]} - 1\right\}, \simeq \frac{\tau_1}{4\tau_2} \text{ if } \tau_1 \gg \tau_2 \qquad (5)$$

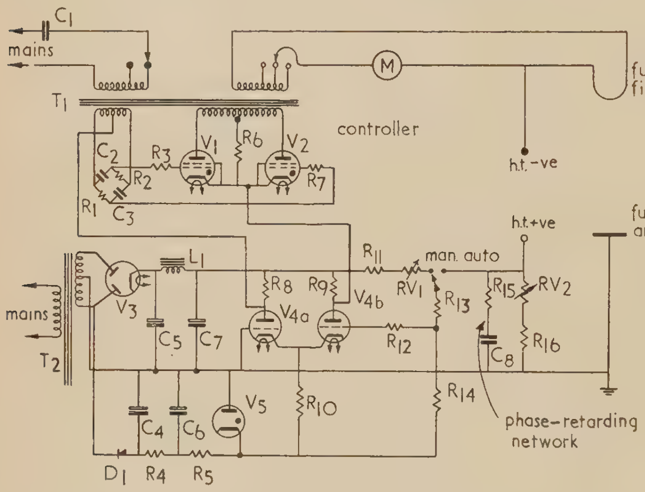
In the emission stabilizer τ_1 is the filament time-constant, typically 0·1–0·2 s, whilst τ_2 is due to the statistical delay of up to half-a-cycle in the controller: for 50 c/s operation its mean value is 5 ms, and hence a loop gain of only 4·5 can be applied before the indicial response becomes under-damped. System stability, combined with high loop gain, can always be realized by the addition of a dominant time-constant of appropriate value, but since for a given damping factor the response time is proportional to the second longest time-constant, it is preferable to increase the effective value of τ_1 by means of a suitable electrical network in the loop. This is the method employed in the stabilizers described in this paper.

STABILIZER FOR A 250 W FURNACE

This unit was designed for use with a small experimental furnace in which the charge, in wire form, was continuously melted by being fed against the hearth, the latter forming the furnace anode.

The mean filament power required was some 50 W. A standard capacitor value of 16 μF gives P_{max} nearly 120 W and this was considered adequate. The type 20A2 tetrode thyratron meets the power-handling requirements with an adequate safety margin, and its high control ratio makes a desirable contribution to the loop gain.

Fig. 2 shows the essential circuitry. Fixed quadrature bias for the thyratrons is obtained from an auxiliary winding on the control transformer: this ensures correct phasing and also automatically reduces the grid voltage once the thyratron has fired. The emission current is measured by passing it through a variable measuring resistor $R_{16}RV_2$, the voltage thus produced being compared with a 150 V neon-stabilized reference source *via* divider R_{13}, R_{14}. A simple single-stage differential amplifier $V_{4a,b}$ amplifies the error signal, which is fed to the thyratrons by "floating" the whole controller across V_4 anodes. The loop gain in this stabilizer is low, since it was required only to prevent the "runaway" condition, but the emission is nevertheless held stable to within a few per cent. A phase-retarding network R_{15}, C_8 is included, and provision is made for manual control of emission by RV_1.



R_1, R_2 = 33 kΩ
R_3 = 100 kΩ
R_4, R_5 = 2·2 kΩ
R_6 = 470 Ω, 10 W
R_7 = 100 kΩ
R_8, R_9 = 12 kΩ
R_{10} = 7·5 kΩ
R_{11} = 100 kΩ
R_{12} = 1 MΩ
R_{13} = 33 kΩ
R_{14} = 100 kΩ
R_{15} = 2·7 kΩ
R_{16} = 250 Ω, 10 W

RV_1 = Manual control, 50 kΩ
RV_2 = Auto control, 500 Ω, 10 W

C_1 = 16 μF, 500 VW paper
C_2, C_3 = 0·1 μF
C_4 = 32 μF
C_5 = 8 μF

C_6 = 32 μF
C_7 = 16 μF
C_8 = 50 μF

V_1, V_2 = 20A2
V_3 = UU9
$V_{4a,b}$ = 12AU7
V_5 – 150C2

M = 10 A a.c.

T_1 = Control transformer
N1 = 10
N2 = 3
T_2 = Mains transformer, 250–0–250 V, 60 MA

L_1 = 20 Hy., 60 mA

D_1 = DRM1B

Fig. 2. Circuit of 250 W stabilizer

AN EMISSION STABILIZER FOR A 6 KW ZONE-MELTING FURNACE

Circuit details. This stabilizer (Fig. 3) was designed for precise control of emission in a zone-melting furnace, operating at emission currents up to 2 A and anode voltages up to 3 kV, the P_{max} figure being in the region of 1·5 kW. At power levels of this magnitude the capacitor values become large, and the design is almost always influenced by available capacitor ratings. In this case a 100 + 100 μF C_1, C_2 power-factor correction capacitor was employed, although the calculated requirement was for 235 μF. A pair of type BT19 thyratrons V_1, V_2 (P_{max} = 1·75 kW) suffices for control, but provision is made for larger valves to allow for possible development. The transformer ratio is 5 for both N_1 and N_2, but the N_1 winding was provided with multiple tappings to facilitate the testing of differing filament structures.

The general pattern of the circuitry follows that of t lower-power stabilizer, but certain refinements were nece sitated by the requirement for more precise control and t higher power level. For example, the existing high tensi supply was insufficiently smoothed to prevent the insta taneous anode voltage falling below the temperature-limit threshold at currents above an ampere or so, and the con plete smoothing of the supply would have been uneconom Hence a filter has been incorporated to eliminate the 100 c ripple which may appear across the reference resistor. Th difficulty can, of course, be avoided by the use of polypha high tension supplies. The measuring and reference circu and the error amplifier are basically similar to those in t low-power stabilizer, but four overlapping current rang are provided with a fine control (RV_1), whilst the gain of t amplifier (V_6–V_7) is much higher.

The ripple filter referred to is an active network: V_8 an V_9 form a narrow-band phase-reversing amplifier which h unity gain in the 100 c/s region, the gain outside this bar being much less than unity. Hence the addition of the filt amplifier output to the unmodified error signal effects ca cellation of ripple-frequency components. A preset contr RV_2 allows the degree of rejection to be adjusted to t minimum consistent with satisfactory operation; in this wa the closed-loop performance is degraded no more tha absolutely necessary.

The filtered input signal is compared with the referen voltage across V_5, and amplified by the long-tailed pa V_6, V_7. In normal closed-loop operation the thyratron V_1, V_2 are driven by cathode-followers $V_{4a,b}$, which in tu are directly coupled to the anodes of V_6 and V_7.

In any control system the realization of a response tim shorter than that inherent in the controlled element pr supposes the availability of peak power much in excess normal quiescent requirements. There is thus a real dang of destroying the furnace filament if the system is switche on with the filament cold, or with a high tension volta lower than that required to operate the furnace under ter perature-limited conditions. Hence provision for manu control is incorporated (S_2) and a second cathode-follow pair $V_{10a,b}$, permanently driven from V_6, V_7 feeds a cent zero d.c. meter, the deflexion of which is a measure of t error voltage. In operation the desired emission current first established manually and then the auto-emission contr is set to null the error meter; the manual-automatic transitic

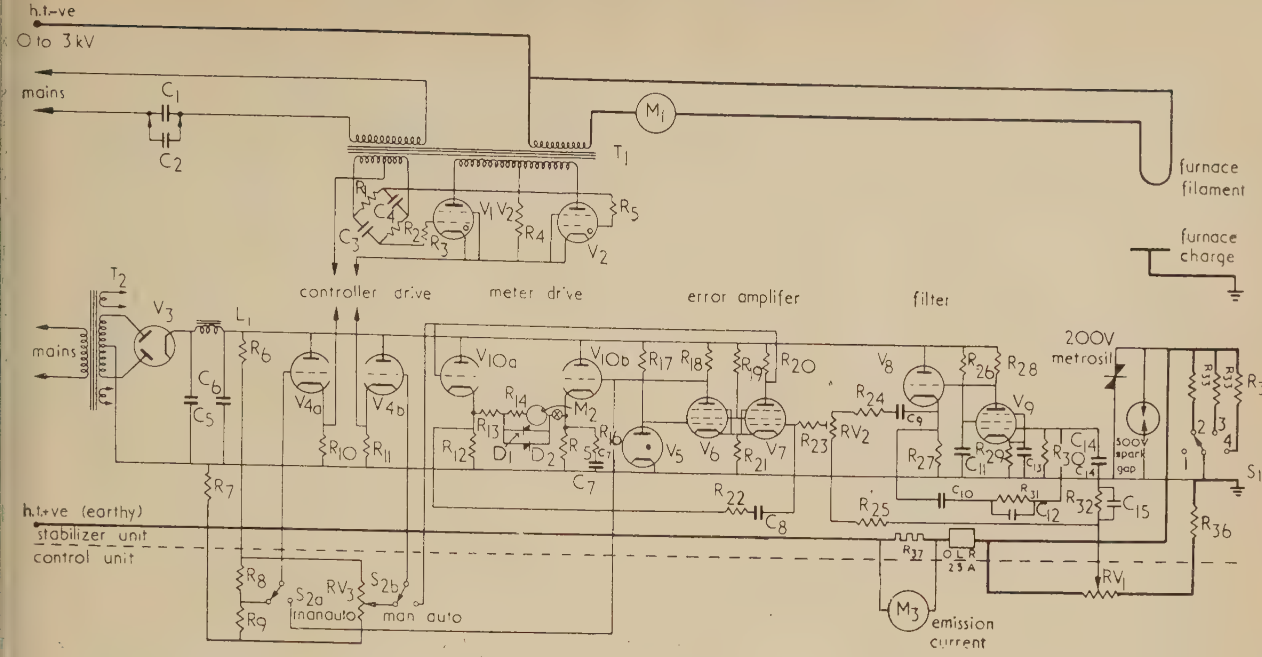

h.t.-ve
0 to 3 kV
mains
C1
C2
M1
T1
furnace filament
furnace charge
R1
C4
C3
R2
R3
V1 V2
R4
R5
V2
T2
V3
controller drive
meter drive
error amplifier
filter
mains
L1
R6
C6
C5
V4a
V4b
R10
R11
V10a
V10b
R17
R18
R19
R20
V8
R26
R28
200V metrosil
R33
R34
R35
R14
M2
R13
R12
D1
D2
R15
C7
R16
V5
V6
R21
V7
R23
R24
C9
RV2
V9
R27
C11
R29
C13
R30
C14
500V spark gap
1 2 3 4
S1
R7
C7
R22
C8
R25
C10
R31
C12
R32
C15
R36
h.t.+ve (earthy)
stabilizer unit
control unit
R37
O.L.R. 2.5 A
RV1
R8
S2a
RV3
S2b
R9
man auto
man auto
M3
emission current

Fig. 3. Stabilizer for 6 kW furnace

C_1, C_2 = 100 μF
C_3 = 1 μF
C_4 = 1 μF
C_5 = 8 μF
C_6 = 16 μF
C_7, C_8 = 0·4 μF
C_9 = 32 μF
C_{10} = 1 μF
C_{11} = 0·1 μF
C_{12} = 0·02 μF
C_{13} = 50 μF
C_{14} = 0·1 μF
C_{15} = 0·002 μF

V_1, V_2 = BT19
V_3 = UU9
$V_{4a,b}$ = 12AU7
V_5 = 90C1
V_6, V_7 = EF86
V_8 = 6L18
V_9 = EF86
$V_{10a,b}$ = 12AU7

M_1 = 40 A meter
M_2 = error meter 500–0–500 μA
M_3 = 1 mA meter

S_1 = Coarse range switch
S_2 = Auto manual switch

T_1 = Controller transformer, $N_1 = N_2 = 5$
T_2 = Mains transformer, 350–0–350 V, 120 mA

R_1, R_2 = 3·3 kΩ
R_3 = 1 kΩ
R_4 = 20 Ω
R_5 = 1 kΩ
R_6 = 56 kΩ
R_7 = 47 kΩ
R_8–R_{11} = 22 kΩ
R_{12} = 47 kΩ
R_{13} = 47 kΩ
R_{14} = 1 kΩ

R_{15} = 47 kΩ
R_{16} = 10 kΩ
R_{17} = 47 kΩ
R_{18} = 100 kΩ
R_{19} = 180 kΩ
R_{20} = 100 kΩ
R_{21} = 33 kΩ
R_{22} = 10 kΩ
R_{23} = 1 MΩ
R_{24} = 100 kΩ, h.s.
R_{25} = 100 kΩ
R_{26} = 680 kΩ
R_{27} = 15 kΩ
R_{28} = 220 kΩ
R_{29} = 2·2 kΩ

R_{30} = 470 kΩ
R_{31}, R_{32} = 15 kΩ
R_{33} = 900 Ω
R_{34} = 360 Ω
R_{35} = 190 Ω
R_{36} = 360 Ω
R_{37} = 1 amp shunt

RV_1 = 500 Ω, 40 W, emission current
RV_2 = 15 kΩ, set rejection
RV_3 = 50 kΩ, manual control

D_1, D_2 = B.T.H. Type SJD1

L_1 = 20 henries, 120 mA

ay then be effected without discontinuity. Silicon diodes $_1$, D_2 across the error meter provide effective overload rotection whilst maintaining almost full sensitivity in the ull region. The fluctuations of the error voltage meter orm a useful indication of the stability of emission under losed-loop conditions.

The phase-retarding network C_8–R_{22} makes use of the Iiller effect in V_7 to lengthen the filament time constant by a actor of one hundred. This arrangement avoids the use of large capacitor and is also self-compensating against gain ariations in the error amplifier.

Performance. This controller has been in service for some ighteen months during which time the furnace has been sed for zone-melting of molybdenum, rhenium, titanium nd tungsten; the latter metal, particularly, could not be satisfactorily processed before the stabilizer was installed. Fig. 4 shows typical ingots after treatment under manual and stabilized conditions.

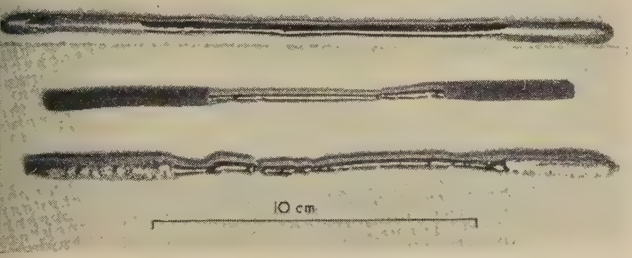


Fig. 4. (*a*) Molybdenum ingot, zone-melted with stabilizer operative. (*b*) Tungsten ingot, zone-melted with stabilizer operative. (*c*) Molybdenum ingot, zone-melted with manual control of emission

Under conditions of normal outgassing the emission remains constant to within less than ±0·5%. With severe outgassing, flashovers may occur causing momentary emission changes, but in most cases the system retains control. Materials with large gas content are normally processed in a number of successive "passes"; with such materials flashovers may be frequent, and it has been found necessary to install Metrosil protectors, backed up by a spark gap, across the measuring resistor.

CONCLUSIONS

Stabilization of emission almost always enables improved performance to be obtained from a bombardment furnace; in some cases, manual operation is not possible. It is desirable that the furnace should operate in a temperature-limited mode to permit independent adjustment of emission and power input. The basic system devised for control of temperature-limited emission has to be proved to be designable and highly flexible, whilst having wide control range, fast response, and high gain. The upper limit of power handling capacity is likely to be limited to some 20 kW by available line input capacitor ratings.

ACKNOWLEDGEMENTS

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Three-beam interferometer

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The instrument described utilizes a beam dividing system similar to that used in the Jamin interferometer, but employs three interfering beams instead of two. This permits the determination of the fractional fringe order with an extremely high degree of accuracy. It can be used for studying very small changes of refractive index in gases and liquids, and, in a slightly modified form, as an auto-collimating interferometer for the precise measurement of the thickness of evaporated films.

The two types of interferometers which have been most commonly used for the measurement of small path differences are the Rayleigh interferometer(1) and the Jamin interferometer.(2) Of these, the Jamin interferometer has several obvious advantages—the spacing of the fringes can be easily controlled, the light paths are separated by a convenient distance, and the aperture is fairly large, resulting in a reasonably bright fringe system. Against these, the major drawback of this type of interferometer has been the fact that it is not possible to make very precise settings on the fringes. This is partly because the intensity distribution in the fringe system is sinusoidal, resulting in rather diffuse fringes, and partly because it is not easy to introduce a reference fringe system in the field, as is possible with the Rayleigh interferometer.

These drawbacks have been eliminated in the interferometer described in the present paper by making use of three interfering beams instead of two. The arrangement adopted retains all the advantages and simplicity of the Jamin interferometer, while permitting estimation of the fractional fringe order with an extremely high degree of accuracy.

BASIC OPTICAL SYSTEM

The layout of the interferometer is shown schematically in Fig. 1. The two beam dividers M_1, M_2 are identical optical glass blocks whose faces have been worked plane and parallel. The inner faces are coated with a semi-reflecting film of aluminium, while a part of each of the outer faces (shown by a thick line in the diagram) is coated with an opaque, fully reflecting layer. Stops S_1 and S_2 serve to define the incoming and outgoing beams, and a mask having three apertures separated by suitable distances used to isolate the three beams which are formed by multip reflection at M_1. After passing through the cells C_1–C these beams are recombined by reflection at M_2. If w assume that the reflection and transmission coefficients c the inner face of the beam dividing plates are r and t respec tively, and the reflection coefficient of the aluminium coatin on the outer faces is R, it is easily seen that the intensities c the three beams are equal and given by the expressio $I_0R^2r^2t^2$ where I_0 is the intensity of the beam incident on M The fringe system formed by interference of these three beam can be viewed either with the naked eye or through telescope T.

In practice, it is most convenient to use the two oute beams as reference beams, with the sample cell in the centra beam. The preliminary adjustment of the interferometer i then easily carried out, using the same procedure as tha followed for the Jamin interferometer,(3) after blocking ou the central beam. With white light, when the two plate M_1, M_2 are strictly parallel to each other, a single brigh fringe will appear to cover the whole field, and upon tiltin one of the plates very slightly about an axis lying in th plane of the paper, a system of coloured horizontal fringe will appear, centred about the white zero-order fringe.

THEORY OF THE INTERFEROMETER

The intensity distribution in the fringe system formed by a three-beam interferometer of this type can be easily visualize by considering the amplitude at any point in the pattern a

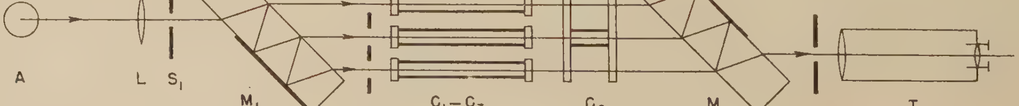

Fig. 1. Schematic diagram of the interferometer

A, source; *L*, condensing lens; M_1, M_2, beam dividing mirrors; S_1, S_2, S_3, stops; C_0, compensating cell; C_1–C_3, gas cells; *T*, telescope.

resultant of the amplitudes arising from the fringe system med by the two outer beams and the coherent background to the middle beam.(4) Accordingly, if we ignore the cts of the phase coherence factors of the three beams, it be shown(5) that the intensity distribution in the inter-ence pattern is given by the relation

$$I(x_1\ \phi) = I_0[3 + 2\cos(2\pi x/a) + 4\cos(\pi x/a)\cos\phi] \quad (1)$$

ere x is the distance from the centre of the pattern, a is fringe spacing, and ϕ is the phase difference between the tral beam and the two outer beams.

Thus, the introduction of the middle beam results in a ange in the intensity distribution of the fringes which pends upon the path difference between the middle beam l the outer beams. Fig. 2 shows the intensity distribution the pattern for three different values of ϕ, while Fig. 3 is photograph of the actual interference fringes obtained der these conditions. It is seen that when the central beam is either in phase or out of phase with the outer beams, its effect is to alternately weaken and reinforce the fringes, while all the fringes have the same intensity when the phase difference between the central beam and the outer beams is equal to $\pi/2$. In the latter case, a very small change in the phase of the central beam results in a noticeable difference in brightness between adjacent fringes.(4) Consequently, this criterion can be used as a very sensitive null setting, in conjunction with some form of optical compensator.

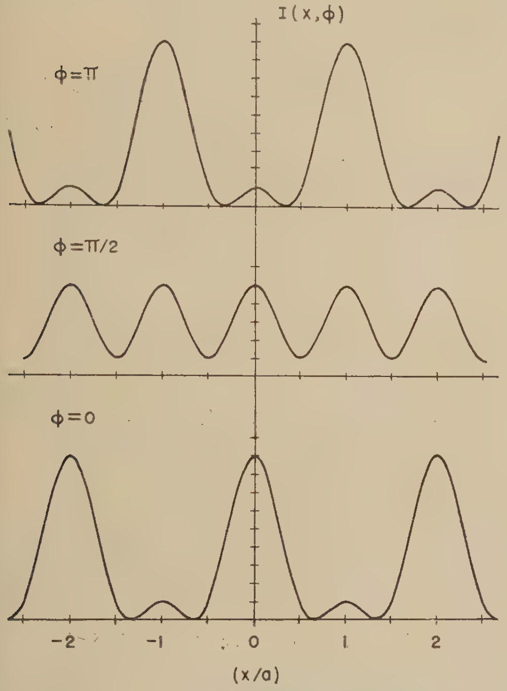

Fig. 2. Intensity distribution in the interference pattern for various values of the phase difference ϕ between the central beam and the outer beams

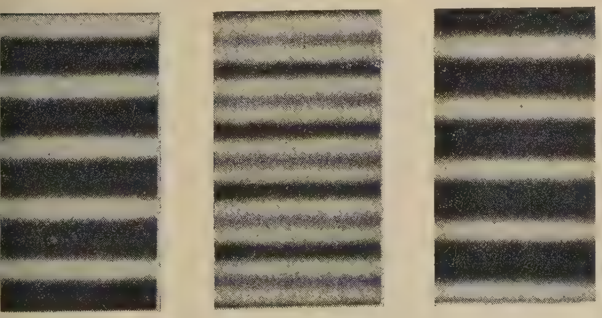
$\phi=0$ $\phi=\pi/2$ $\phi=\pi$

Fig. 3. Photographs of the fringes obtained with various values of the phase difference ϕ between the central beam and the outer beams

The most suitable form of compensator for this purpose was found to be an auxiliary cell in the central beam, containing a gas whose pressure could be varied by means of a piston controlled by a micrometer screw. The pressure in the cell was measured with a mercury manometer and a travelling microscope.

For a cell with a length of 1 cm filled with air, it can be easily shown that a change in pressure of 1 mm corresponds to a change in the optical path of approximately $\lambda/100$. Thus, such a cell constitutes a very sensitive compensator. It also has the advantage that it can be used to introduce negative as well as positive path differences.

PERFORMANCE

Actual measurements carried out under laboratory conditions showed that settings could be repeated to an accuracy of about $\lambda/200$ by visual judgment of the equality of brightness of a pair of adjacent fringes, while an accuracy of the order of $\lambda/1000$ could be obtained by using photoelectric detection techniques, to which this interferometer is particularly suited. (Some of the methods which can be utilized for this purpose will be discussed in Part II of this paper.) Due to the symmetrical arrangement of the two reference beams, the fringes were found to be extremely stable and free from drifts, provided care was taken to avoid temperature gradients.

MODIFICATIONS

While the interferometer as described above is very suitable for measurements of changes in the refractive indices of gases and liquids, there are many problems for which an autocollimating arrangement would be advantageous. Two

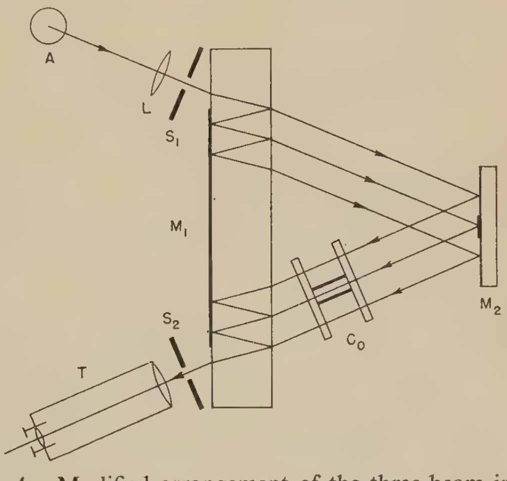

Fig. 4. Modified arrangement of the three-beam interferometer using a single plane-parallel plate as the beam divider

A, source; *L*, condensing lens; M_1, beam dividing plate; M_2, end mirror; S_1, S_2 stops; C_0, compensating cell; *T*, telescope.

modifications of the basic optical system which can be utilized for such purposes are described below.

The first, shown in Fig. 4, utilizes a single, thick, plane-parallel plate M_1 as the beam dividing element.(6) One face of this plate is coated with a semi-reflecting film, while the opposite face has an opaque, reflecting strip down the middle. Two slits S_1, S_2 serve to define the incoming and outgo beams. This type of three-beam interferometer can be v easily set up and adjusted, but it has two disadvantag One is that the beams are incident at an angle on the mirror M_2, while the other is that the working space betw the two mirrors is rather limited.

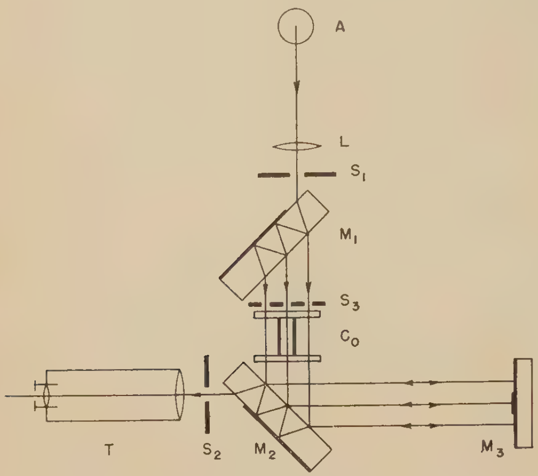

Fig. 5. Autocollimating modification of the three-beam interferometer

A, source; *L*, condensing lens; M_1, M_2, beam dividing mirrors; M_3, end mirror; S_1, S_2, S_3, stops; C_0, compensating cell; *T*, telescope.

Both these drawbacks are avoided in the set-up shown Fig. 5, which utilizes two identical plates M_1, M_2 similar those used in the original interferometer, to divide a re-combine the three beams. With this arrangement, the e mirror M_3 can be placed at any convenient distance from diagonal mirror M_2. Several applications can be envisag for an interferometer of this type, one being the measurem of the thickness of an evaporated film during the coati process.

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Photoelectric setting methods for a three-beam interferometer

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Some of the photoelectric methods which can be applied to estimate the fractional fringe order in the three-beam interferometer described in the preceding paper(1) are outlined, and their comparative merits are discussed. Experimental measurements show that with the help of such methods settings can be repeated to better than $\lambda/1000$, provided care is taken to minimize temperature fluctuations.

Since the accuracy of any interferometric measurement depends largely on the precision with which the fractional fringe order can be estimated, considerable attention has been devoted recently to the development of photoelectric setting methods which can be used for this purpose.(2–5) However, the application of such techniques to conventional two-beam interferometers has been largely restricted by the fact that most of the methods which can be used with them are relatively complicated and do not yield any great increase in accuracy over visual settings.

On the other hand, photoelectric techniques can be applied very easily to the three-beam interferometer described in the preceding paper(1) to permit extremely precise measurements of the fractional fringe order. Accordingly, we shall discuss, in the next few sections, some of the methods which can be used with an interferometer of this type and attempt an analysis of their comparative merits.

THEORETICAL CONSIDERATIONS

The photoelectric setting methods which can be applied to the three-beam interferometer can be divided into two basic groups, those using intensity modulation of the beams and those using phase modulation. However, since the thre beam interferometer offers no particular advantages, as f as phase modulation methods are concerned, over a co ventional two-beam interferometer, and also since the generally require rather elaborate experimental arrangemen we shall consider only intensity modulation methods detail. These can be further subdivided into two groups those using intensity modulation of the central beam an those using intensity modulation of the outer beams.

(*a*) *Intensity modulation of the central beam.* If we negle the effects of the phase coherence factors of the beams, th intensity distribution in the fringe system formed by a thre beam interferometer of this type is given by the relation

$$I(p, \phi) = 2I_0[1 + \cos 2\pi p] + I_0[1 + 4 \cos \pi p \cos \phi]$$

where $p = x/a$, x being the distance from the centre of th pattern and a the fringe spacing, I_0 is the intensity correspon ing to one beam, and ϕ is the phase difference between th central beam and the two outer beams. On the other han the intensity distribution due to the two outer beams alon when the central beam is cut off, is given by the expressi

$$I'(p, \phi) = 2I_0[1 + \cos 2\pi p]$$

Thus, at any given point in the pattern, the introduction the middle beam results in a change in the intensity which pends upon the path difference between the middle beam d the outer beams. It is easily seen that this change is ro at any point in the pattern, in general, when

$$\cos\phi = -\tfrac{1}{4}\cos\pi p \qquad (3)$$

d, at the centre of the pattern ($p = 0$) in particular, when

$$\cos\phi = -\tfrac{1}{4} \qquad (4)$$

at is to say, when the phase difference between the central am and the outer beams is equal to ±104° 30′.

This condition is diagrammatically illustrated in Fig. 1, in ich the vector OA ($=2I_0$) represents the resultant ampli-de at the centre of the pattern due to the two outer beams, ile the vectors OB, OB' represent the two solutions of uation (4) for which the resultant amplitudes OC, OC' due the three beams are equal to OA.

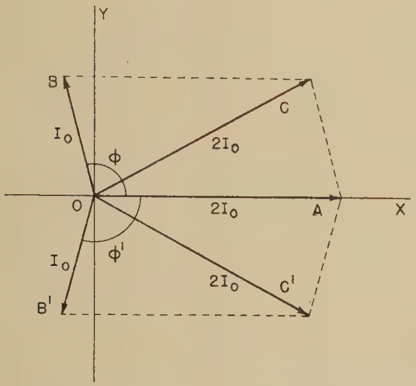

Fig. 1. Vector diagram illustrating the condition for no change in intensity at the centre of the interference pattern when the central beam is modulated

This condition can be made use of for photoelectric setting n conjunction, of course, with a suitable form of compen-tor) by placing a fine slit at the centre of the pattern and easuring the fluctuations in the light transmitted by this it with a photomultiplier, when the central beam is alter-ately blocked out and let through.(6, 7)

However, this method, while attractive in principle, suffers om two disadvantages. The first is that since the actual nount of light transmitted by such a narrow slit is quite nall, it is necessary, in practice, to use a fairly wide slit entred on the middle fringe. This results in a change in the nase of the middle beam corresponding to the null setting. hus, if we use a slit having a width equal to half the fringe acing, the change in the light flux incident on the detector hen the central beam is cut off is given by the equation

$$\Delta F = I_0\int_{-1/4}^{1/4}(1 + 4\cos\pi p\cos\phi)dp$$
$$= I_0[(1/2) + (4/\pi\sqrt{2})\cos\phi] \qquad (5)$$

hich is zero when $\phi = \pm 123° 44'$.

Another drawback of this method is that any shift in the inge system with respect to the slit also results in a change the phase of the central beam corresponding to the null tting. This is evident from equation (3), from which it can seen that for a narrow slit a displacement of 0·1 of the inge spacing from the centre of the pattern will result in error of approximately $2\pi/100$ in the value of ϕ. Hence, hen using this method, it is essential to adjust the slit of the photoelectric detector so that it is centred exactly on the zero order fringe, before every setting.

(*b*) *Intensity modulation of the outer beams.* In this method, the two outer beams are alternately cut off, either by means of a vibrating slit or a rotating sector, so that the interference pattern seen in the field changes rapidly from that due to the central beam and the left beam, to that due to the central beam and the right beam.

We can represent the intensity distribution in the fringe system due to the central beam and the left beam by the relation

$$I_1(p, \phi) = 2I_0[1 + \cos(2\pi p + \phi)] \qquad (6)$$

and that due to the central beam and the right beam by the relation

$$I_2(p, \phi) = 2I_0[1 + \cos(2\pi p - \phi)] \qquad (7)$$

Thus, the effect of chopping the outer beams is to cause the fringes to oscillate with an amplitude Δp given by the relation

$$\Delta p = (\phi/\pi) \qquad (8)$$

This obviously becomes equal to zero when ϕ is equal to zero, so that this can be used as a setting criterion, in conjunction with some photoelectric method of detecting the movement of the fringes.

One method of doing this is to use a slit which is located asymmetrically with respect to the centre of the fringe system as shown in Fig. 2(*a*). Any small movement of the fringes will then cause a change in the flux transmitted by the slit.

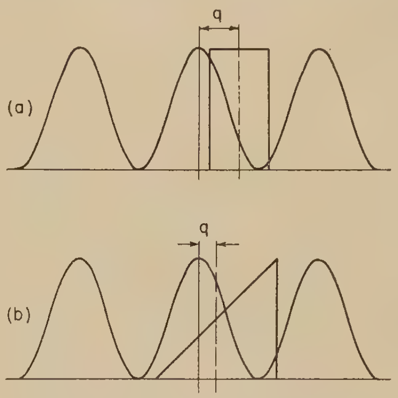

Fig. 2. (*a*) Detector using an asymmetricaly located slit. (*b*) Detector using a triangular slit

For a slit having a width equal to half the spacing between adjacent fringes and located with its centre line at a distance q (expressed as a fraction of the fringe separation) from the centre line of the fringe system, the change in flux when the outer beams are chopped is given by the relation

$$\Delta F = 2I_0\int_{q-1/4}^{q+1/4}[\cos(2\pi p + \phi) - \cos(2\pi p - \phi)]dp$$
$$= (4I_0/\pi)\sin\phi\sin 2\pi q \qquad (9)$$

It is easily seen that this change is always zero when $\phi = 0$ or π, corresponding to the null setting. The sensitivity of the detector is obviously a maximum when $q = \pm\frac{1}{4}$ and drops to zero when $q = 0$, that is to say, when the detecting slit is located symmetrically with respect to the zero line.

An alternative method of detecting the movement of the fringes is to use a triangular aperture. For an aperture of this form, one fringe-spacing wide, located as shown in

Fig. 2(*b*), the change in the flux incident on the photomultiplier when the outer beams are chopped is given by the relation

$$\Delta F = 2I_0 \int_{q-1/2}^{q+1/2} [\cos(2\pi p + \phi) - \cos(2\pi p - \phi)](p - q + \tfrac{1}{2})dp$$

$$= (2I_0/\pi)\sin\phi\cos 2\pi q \qquad (10)$$

where q is the distance of the centre of the aperture from the centre line of the fringe system. This is also equal to zero when $\phi = 0$ or π. The maximum sensitivity is obtained in this case when $q = 0$, while the sensitivity drops to zero when $q = \pm\frac{1}{4}$. Thus, this method has the practical convenience that it is possible to view the zero order fringe at any time, without having to move the detector slit.

An important advantage of both these methods is that the phase of the central beam corresponding to a null does not depend either on the width of the slit used, or on its position with reference to the fringe system. The only effect of changing these is to vary the sensitivity. Accordingly, the optimum position of the detecting aperture can be located very easily, before each set of readings, by moving it slowly across the fringe system until the output signal is a maximum.

EXPERIMENTAL SET-UP

The modifications made to the basic three-beam interferometer for measurements using photoelectric settings are shown in Fig. 3. The detecting slit S_0 was mounted on a slide in the viewing telescope so that it could be easily placed in the focal plane of the objective, or removed for preliminary adjustments, while the fringes were examined through t reflex attachment *R*. This could be swung out of the bea after the detecting slit was brought into position. The lig beam passing through the detecting slit was then allowed fall on the photomultiplier *PM* placed just behind the diffus *D*. While it is advantageous for visual observations to ha four or five fringes in the field as an aid to accurate settin a larger fringe spacing is desirable for the photoelectr method, since it permits a wider detecting slit to be use resulting in a stronger signal. Accordingly, in the prese measurements, a fringe spacing *a* of approximately 5 mm w used, along with detecting slits 5 mm high and of appropria width.

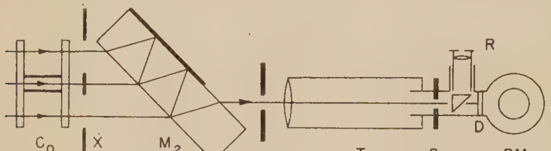

Fig. 3. Modified arrangement of the three beam interferometer for photoelectric setting

C_0, compensating cell; X, chopper; M_2, beam dividing mirror; S_1, stop; *T*, telescope; S_0, detecting slit; *R*, reflex eyepiece; *D*, diffuser; *PM*, photomultiplier.

Intensity modulation of the three beams was effected b means of a vane *X* attached to the armature of a centre-stab relay mounted on a separate support. By using two differe vanes with this relay, it was possible either to chop the centr beam alone, or to cut off the outer beams alternately, at frequency of 5 c/s.

The signal from the photomultiplier was detected with a amplifier tuned to the chopping frequency. The circuit use for this purpose is shown in Fig. 4 and comprises three stage of amplification succeeded by a cathode follower. The outpu from the cathode follower was rectified by means of fou germanium diodes and, after smoothing by a two-stage filte was read on the microammeter *A*. A three-way switch S permitted the sensitivity to be reduced in three steps, to avoi overloading the meter during the preliminary adjustments fo balance.

The frequency response characteristics of the amplifier ar shown in Fig. 5. By using three stages of resistance capac tance filtering to attenuate high frequencies, and by suitab choosing the coupling capacitors, it was found possible t obtain a high degree of discrimination against the 100 c/ signal due to the lamp run off the a.c. mains, without th output, at the same time, being too critically dependant o the chopping frequency.

The actual phase shift of the central beam was measured as before, by means of a gas cell compensator placed in th central beam. The pressure in this cell could be varied b means of a piston controlled by a micrometer screw and wa measured by means of a mercury manometer read with a accurate travelling microscope.

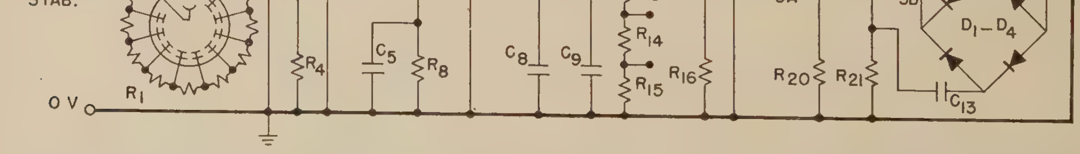

Fig. 4. Circuit diagram of the amplifier. All resistors are ±10%, 1 W, carbon, except where otherwise specified

R_1 = 100 kΩ each
R_2, R_7, R_{11}, R_{12} = 4·7 MΩ
R_3 = 25 kΩ, 5 W
R_4, R_8, R_{13}, R_{16} = 10 MΩ
R_5, R_9, R_{15}, R_{17} = 100 kΩ
R_6, R_{10}, R_{18} = 470 kΩ
R_{14}, R_{20} = 1 MΩ

R_{19} = 20 MΩ
R_{21} = 10 kΩ
R_{22}, R_{23} = 4·7 kΩ

C_1 = 0·1 µF
C_2, C_4, C_5, C_7, C_8, C_9, C_{11} = 0·02 µF
C_3, C_6, C_{10} = 32 µF

C_6 = 32 µF
C_{12} = 0·25 µF
C_{13} = 50 µF
C_{14}, C_{15} = 100 µF

V_1 = VR 105
V_2, V_3 = 12AX7

PM = 931 A

D_1–D_4 = 1N34

S_1 = Single pole, three-way switch

A = 0–500 microammeter

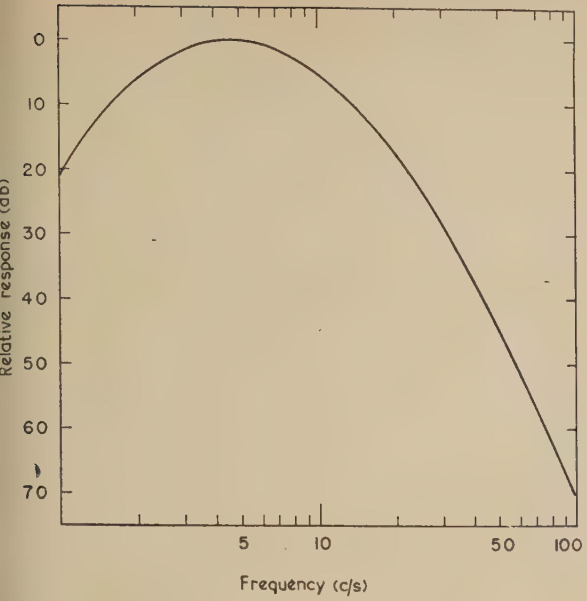

Fig. 5. Frequency response characteristic of the amplifier

EXPERIMENTAL RESULTS

Measurements were carried out using all the three methods photoelectric detection described in the preceding sections. owever, a comparison of the results soon showed the periority of the methods using chopping of the two outer ams, particularly from the standpoint of long-term stability.

With this set-up, it was found that with a Phillips 15 W low pressure mercury arc as the source and a Wratten No. 77*A* filter to isolate the green line, an output current of 200 μA was obtained for a change in the path of the middle beam of approximately $\lambda/200$ with the triangular slit detector, and approximately $\lambda/300$ with the asymmetrical slit, while the output signal due to the background noise was only of the order of 20 μA. It is obvious, therefore, that the accuracy which can be obtained with either of these methods is limited largely by such factors as residual temperature fluctuations, local air currents and building vibrations. In practice, it was found that settings could be repeated to better than $\lambda/1000$, provided care was taken to keep such disturbances to a minimum.

ACKNOWLEDGEMENTS

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Mechanical structure-factor computer

By PROF. W. SCHAFFER, Department of Physics, University of Cape Town, Rondebosch, South Africa

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The construction and use of a machine for computing sums of sine and cosine series, such as those required for structure factors in crystallography, is described. The machine is entirely mechanical and carries out the whole computation. It saves about half the time usually taken and is sufficiently accurate for most purposes.

INTRODUCTION

crystallography (and in other branches of physics and of gineering) it is often necessary to sum series of the form $_{kl} = \sum_j A_j \cos(hx_j + ky_j + lz_j)$. Here x_j, y_j and z_j are the -ordinates of the *j*th atom in the unit-cell and A_j is the attering power of this atom. The co-ordinates are usually fractions of the edges of the unit cell, i.e. in fractions of , and are expressed in sixtieths. Hand computation is ry tedious and electronic machines are seldom available short runs and preliminary trials, so that a simple machine this type is badly needed. The computer described uses mmonly available materials and requires only normal ndards of workmanship. It gives an accuracy of the same der as the familiar two-figure strips.

PRINCIPLE OF COMPUTER

The instrument is shown in Figs. 1 and 2. In Fig. 2 a k *J* can be seen which may be turned about its centre. A all block is pivoted about pin *K*, whose distance from the centre of *J* is adjustable. Block *K* slides in channel *I* which is clamped to rods moving to and fro in guides *P*. If the distance from the centre of the disk to *K* is A_j and the disk turns through an angle θ_j the lateral displacement of *I* will be $A_j \sin \theta_j$. If the angle is $(90° + \theta_j)$ the displacement will be $A_j \cos \theta_j$. A thread is attached to *I*. It passes over a free pulley and then round a second pulley *R* which drives a mechanical counter registering the displacement. The thread is kept taut by a weight or a spring-controlled pulley *W*.

When the counter has registered $A_1 \cos \theta_1$ say, it is locked by means of a brake. The disk is then returned to the zero (vertical) position, the thread slipping over *R* during the adjustment. The brake is released and the displacement $A_2 \cos \theta_2$ is added, and so on for $A_3 \cos \theta_3 \ldots.$ Usually θ_j is a compound angle, such as $(hx_j + ky_j + lz_j)$, where *h*, *k* and *l* are whole numbers. A handle is controlled by an adjustable and by a fixed stop so that a complete stroke of the handle, acting through one of two ratchets (for positive and negative increments respectively), turns *J* through angles x_j, y_j or z_j as the case may be. The handle may be moved

h times to give hx_j or if the multiplication is done mentally the angle hx_j can be described in one stroke. ky_j and lz_j are then added on. The handle is always used the same way to ensure quick and reliable movements. In this way the addition of the terms $hx_j + ky_j + lz_j$, the formation of the sine or cosine and the addition over j are all automatic.

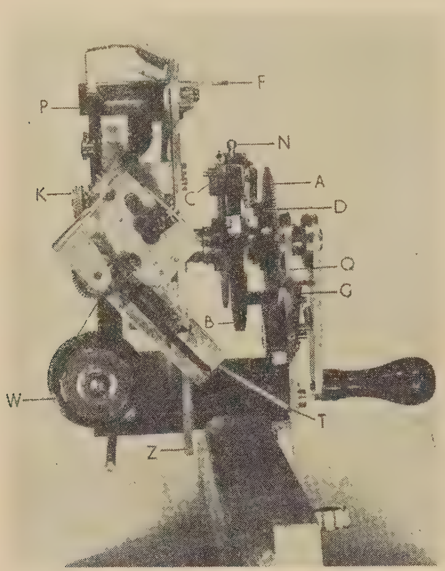

Fig. 1. Side view, showing ratchets and associated parts

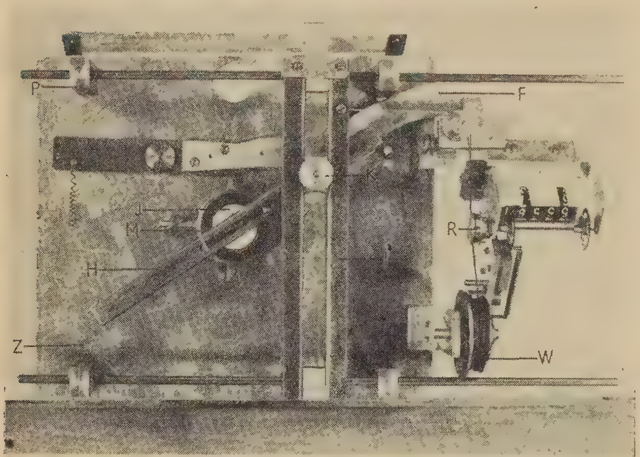

Fig. 2. View showing slides and rods

CONSTRUCTION

Rotating wheels and guides should not be too large or heavy, as a high moment of inertia might cause over-running of ratchet teeth. The over-running can be prevented (if necessary) by the adjustable friction brake *M*. The distance of *K* from the centre of rotation may be varied by slackening the knurled nut and moving it along slide *H*. This distance is made equal to the amplitude A_j and is set on the linear scale on the upper front of the instrument. Block *K* turns about the carefully machined shank of the screw and slides in channel *I*. *I* is made by rubbing down two flat pieces of channel section sheet steel on emery cloth over a plane surface. These two pieces are clamped over two equally thick light spacing blocks at the ends. Shims may be used for adju ment. If wear takes place the side members are remov rubbed flat and replaced. *I* is clamped to two rods wh move freely from side to side in guides *P*. *I* therefore rema parallel to itself. Metal knitting needles make good ro The disk *J* has two notches; when *F* is depressed agai spring tension a projection clicks into one of the notch and *H* is accurately placed either vertically or horizontal as required. *F* turns on an eccentric pivot, so that the fix positions of *H* may be adjusted. Attached to *I* is a leng of cotton thread passing round a pulley driving a mechani counter. Counters from domestic watt-meters are sat factory. The counter may be fitted with a zero-ing dev or may be re-set by hand. It must turn easily and work both directions. The counter has a locking brake—a sm fibre pad which may be pushed against one of the gear whe by lever *T*, working through an eccentric. The pad is pull off by a spring when *T* is in the off position. The thread kept taut by a weight or by a spring-loaded drum. A che tape measure, of the kind that winds up its tape on press a button, may be used here, the cotton being wound on t drum in place of the tape. In practice the cotton drives t counter without observable slip, but slips easily over t pulley when the counter is locked by the brake.

Disk *J* is clamped to its shaft by two grub screws. T shaft turns in a brass bearing in plate *Z*, the chassis of t machine. Another shaft spigotted into this shaft has handle at its end and is supported by a second bearing he in bracket *Q*. The two shafts turn independently but a firmly supported. On the shaft that holds *J* are clamp two ratchet wheels, each with 120 teeth, set for rotation opposite senses. The handle is attached to a shaft on wh is fixed disk *B* carrying a double pawl *C*. By means of lev *N* this can engage either of the two ratchet wheels leav the other free. Disk *B* carries a projection which com against a fixed buffer (attached to bracket *Q*) when turn to the right. A screw through the buffer can be adjust for precise engagement of ratchet teeth. When *B* is turn to the left the projection comes against a buffer *D* which carried by disk *A*. *A* turns on the shaft and can be fix by a lock, which engages some of the 120 teeth when lev *G* of an eccentric is released. *A* has an angular scale, mark in units of 6° each and half units; when it is set at (sa mark 13½ the handle can be turned through 81° and ba on one complete stroke. In this way the ratchet whe engaged by *B* is turned through 81°. On the return stro the handle does not turn the ratchet wheels and is stopp by the fixed buffer. When lever *N* is turned to drive t other ratchet wheel the handle turns freely and drives on t return half of its stroke. Small errors not involving a ratch tooth are not cumulative, giving the machine a partial digital character.

USE OF THE MACHINE

To evaluate $F_{hkl} = A_j \cos (hx_j + ky_j + lz_j)$ procedure as follows: Using the handle and lever *F*, *H* is put into t zero vertical position, and the counter is set to zero. Lever *N* put into position for positive increments, and the angul scale on *A* is set at 15, i.e. 90°, and one stroke is given to t handle, returning it to the fixed stop. *H* is held in positi by using *F*, the knurled nut *K* is loosened and adjusted un the pointer on the scale reads A_1. This adjustment is need only once for each kind of atom. Scale *A* is set to x_1 a the handle given *h* complete strokes. Alternatively, *A* is set the product hx_1 and one stroke is made, and ky_1 and lz_1 a ded in the same way. N is set to the negative side any negative product hx_1, ky_1, lz_1. We now have cos $(hx_1 + ky_1 + lz_1)$. If the sine instead of the cosine is quired the addition of 90° is omitted.

The counter is then locked by means of T and H set to zero position. The counter retains its reading to which term for the next atom is subsequently added. The unter is released, H is turned through 90° for the cosine d through $hx_2 + ky_2 + lz_2$ as before. The counter is cked again to reset H and this is repeated for $j = 3, 4 \ldots n$. e adjustment of A_j is changed when going from one kind of atom to another. The counter gives the sum required. Modifications in the method for sine summation, for product terms (such as $A_j \sin hx_j \cos ky_j$), etc., are easily made.

ACKNOWLEDGEMENTS

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Liquid manometer with electromagnetic balance indicator

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[*Paper received* 4 *July*, 1958]

The paper describes the construction and operation of a null-reading type of liquid manometer, which utilizes an electromagnetic device for balance indication, and a set of analytical weights for indirect "weighing" of the unknown differential pressure. The apparatus was designed specially for measurements in the range of differential pressures below 5 mm water gauge. The probable error under laboratory conditions was found to vary from less than 0·01 mm water gauge at maximum range, to about 0·0005 mm water gauge at a differential pressure of 0·01 mm water gauge. Apart from its normal applications as a manometer, the apparatus can be used as an indicator of the flow dynamic head in low-speed wind-tunnels.

me of the most successful null-reading liquid manometers operation are basically of the U-tube type, in which the quid level in one of the vertical limbs is maintained constant raising or lowering the other limb, together with its liquid olumn, to balance the applied differential pressure. Two ell-known instruments of this type are the Askania inimeter(1) and the Casella micromanometer.(2)

The successful operation of these instruments depends imarily on the accuracy attained in the balance indication d in the relative displacement of the two limbs. An portant secondary requirement for the measurement of ry small pressure differences is that the manometer should ve a reasonably quick reaction time. If long periods ould elapse between zero and pressure readings, appreciable rors could be introduced by evaporation of the liquid, fferential expansion between the liquid and the metal mponents, differential capillary forces at the free surface the liquid columns, and differential density effects in the essure transmission tubes. Most of these effects are due temperature variations.(3)

The manometer described in this paper was developed to ve extreme sensitivity with regard to both functions of alance indication and of limb displacement. This would able an assessment to be made of the limits of accuracy tainable with liquid manometers in the measurement of all differential pressures.

DESIGN AND OPERATION

The design and operating principles of the manometer are scribed with reference to the schematic sketch in Fig. 1. he two vertical limbs of the basic U-tube design are replaced containers A and B respectively, of which the former is xed to the base-plate of the instrument. The movable ontainer B is supported by two identical sets of thin metal bes C and D which deflect when a weight W is placed on e scale pan S. For small deflexions, the vertical displace-ent of container B will be proportional to the load on the scale pan. Since the two sets of tubes are identical, B will furthermore remain in a vertical attitude.

Tubes D are filled with liquid, and serve as the horizontal limb of the U-tube arrangement. Tubes C permit the transmission of pressure from the movable container to the fixed connecting nipple at P_2, the other nipple being at P_1 on the fixed container A. An unknown differential pressure applied to the nipples is balanced by maintaining the liquid column in A at a constant level, and by loading the scale pan until the movable container and its liquid column have been displaced by the required amount. It will now be clear that the nipple at P_2 should not be mounted directly on the movable container B, where the weight of the pressure connecting tube will cause an additional deflexion, the magnitude of which cannot be accurately determined.

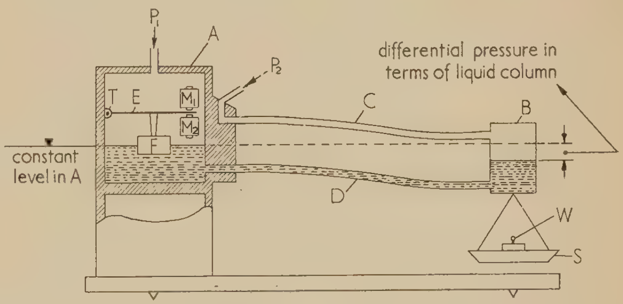

Fig. 1. Schematic representation of the manometer

The liquid level in the fixed container A is indicated by means of an electromagnetic device. A float F is rigidly connected to a mild-steel beam E, which is supported in a frictionless fashion by a torsion wire T at one end. The free end of E moves in the air gap between the two sets of poles of electromagnets M_1 and M_2, which are incorporated in two arms of an a.c. bridge network, of the type evolved by Cox,(4) and illustrated in Fig. 2. Four metal rectifiers are

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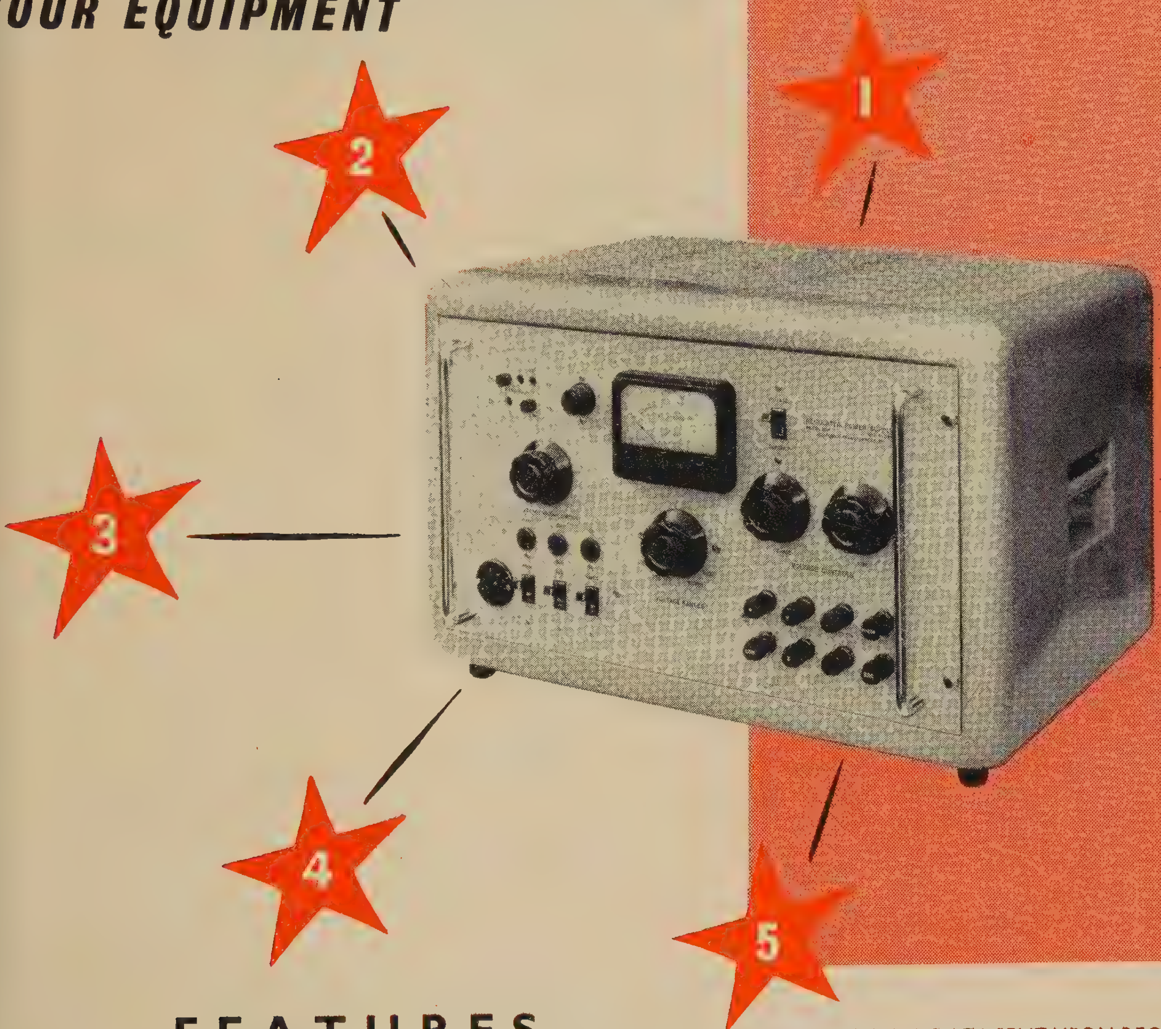

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ould be entrapped in the passages leading from the liquid ntainers to the lower set of flexible tubes. This difficulty uld be overcome by using two single tubes of larger bore, stead of the two sets of thinner tubes. (The original otive for employing thinner tubes had been to facilitate sitive clamping of their ends over a relatively short stance.)

The second problem is associated with corrosion of metal mponents when distilled water is used in the manometer. periments are at present under way with other liquids at may be more favourable than water in this respect. far machine oils and silicones, having viscosities comrable with that of water, have been tried with good success.

ACKNOWLEDGEMENTS

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Two-layer anti-reflexion coating for low refractive index glass

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A method is described for producing durable two-layer anti-reflexion coatings on low refractive index (approximately $1\cdot5$) glasses. Practical difficulties in evaporating absorption free films of high index materials are avoided by reactively sputtering a bismuth oxide film which is then coated with an evaporated magnesium fluoride film. The initial oxide layer is prepared by sputtering bismuth in oxygen from sector-shaped cathodes placed under a rotary holder, and the magnesium fluoride is evaporated in sequence from a vapour source arranged under the edge of the rotary holder. To reduce the reflectance of a glass ($n = 1\cdot5$) at a specified wavelength in the visible region, the bismuth oxide is deposited until the glass reflectance has risen to 8% and the magnesium fluoride evaporated until the reflectance falls to a minima ($R < 0\cdot1\%$). Curves are given for the reflectance of the two-layer coating in the visible region. A simple method of monitoring the wavelength of the reflectance minima is described. It is shown that the wear resistance of the two-layer coating is equal to that of a single-layer magnesium fluoride film and is improved by baking at 250° C.

reduce the reflectance of a glass of low refractive index pproximately $1\cdot5$) to zero at a given wavelength with a 4-film requires a film material with an index of about 23, whereas dielectric materials which are capable of rming durable evaporated coatings, such as magnesium ioride, have indices above $1\cdot3$. Consequently, it has not en practical to efficiently reduce the reflectance of a low dex glass with a single-layer film. Several types of multiyer interference systems have been proposed for use on low dex glass requiring the deposition of high and low index aterials. However, such systems have not completely ercome the problem because it has proved difficult to aporate high index films which are both durable and free om optical absorption. Zinc sulphide films are currently ed as high index layers in multi-layer filters but they are t sufficiently durable for use in anti-reflectance layers on e exposed surfaces of optical elements. Vogt⁽¹⁾ and later ass⁽²⁾ have prepared durable films of high index by aporating cerium dioxide, but this substance requires very gh temperatures for its volatilization and elaborate preeatment before it can be evaporated at a controlled rate.

The authors have attempted to overcome these problems using high index films of bismuth oxide prepared by uttering bismuth in oxygen, because such films are reasonly durable and their deposition rate is easy to control. Holland⁽³⁾ has described a vacuum plant with which it is possible to sputter and evaporate thin films on to the same work-holder in sequence and this apparatus has been adapted for preparing two-layer anti-reflexion coatings of sputtered bismuth oxide and evaporated magnesium fluoride. Given below is an account of the preparation and properties of these anti-reflexion coatings using the modified apparatus.

EXPERIMENTAL APPARATUS

The apparatus used for depositing the two-layer antireflexion coatings is shown in Fig. 1. The glass to be coated is mounted on a rotary work holder above a pair of sector-shaped cathodes for sputtering and a molybdenum boat for evaporation.

The sputtering electrodes, shown in detail in Fig. 2, are of sector shape and made from $\frac{1}{8}$ in. thick copper sheet on which bismuth has been spread whilst in the molten state. Copper piping is brazed to the underside of the electrodes for water cooling to prevent the bismuth melting during sputtering. The cooling water for each sector electrode is taken in and out of the chamber by a pair of concentric tubes which pass through a vacuum sealed and insulated lead-in electrode in the base-plate. The cooling pipes on each sector cathode are connected inside the vacuum chamber to the water supply tube by a union with a rubber O-ring seal.

The sector electrodes are connected to the output terminals of a high tension a.c. transformer and operate as cathodes which sputter on to the work holder on alternate cycles. The underside of the sector cathodes and the outside of the water-cooling tubes are screened with earthed plates mounted within the cathode dark space to prevent sputtering of the copper fittings.

When the sector cathodes are mounted on the same plane the glow discharge at the tips of the electrodes is partially suppressed, owing to the electrons in the cathode dark space being obstructed by the electrode serving as the anode on alternate cycles. This decreases the sputtering rate at the centre of the electrode so that the deposited film is thinner at the centre. The effect is avoided by mounting the two electrodes on separate levels, as shown in Fig. 1, so that each electrode does not hinder the cathode dark space of the other. The sector electrodes are arranged so that they do not unduly impede the vapour stream arriving at the rotary holder from the vapour source arranged under the edge of the holder. If the electrodes are mounted near to the work holder the centre of the evaporated deposit shows a series of concentric rings of different interference colours where the electrodes cast shadows on the holder.

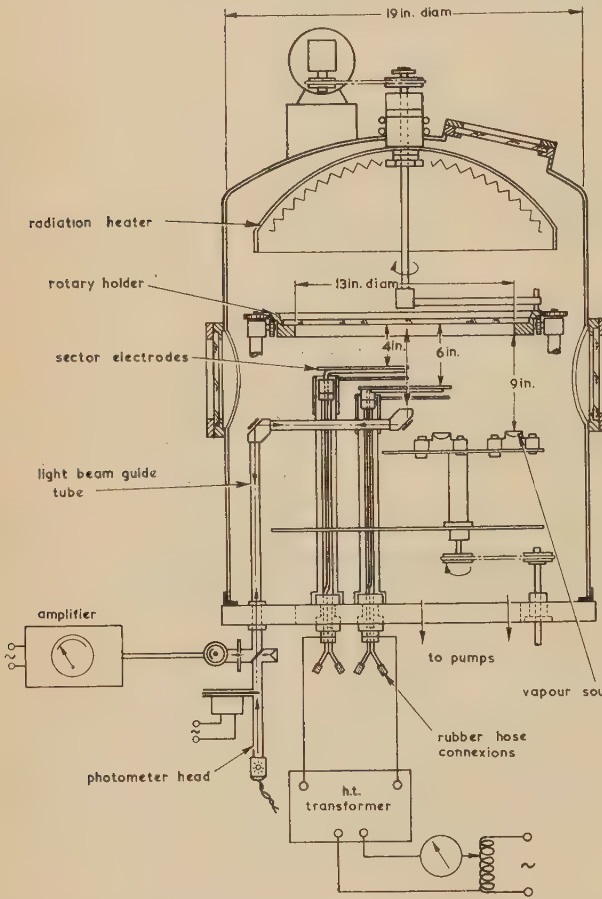

Fig. 1. General arrangement of combined sputtering and evaporation plant for two-layer anti-reflexion coating

It has been found that sputtered bismuth oxide films are free from light absorption, providing they are sputtered at a high current density with oxygen continuously flowing through the coating vessel. Satisfactory conditions were obtained with a current density of 10 mA/cm^2 of electro
area and an applied voltage of 3 kV. Using the dimensio
shown in Figs. 1 and 2, the oxide was deposited at a ra
of 1 Å/s.

The thickness of the deposits was controlled by measurin
their reflectance during deposition using a modulated bea

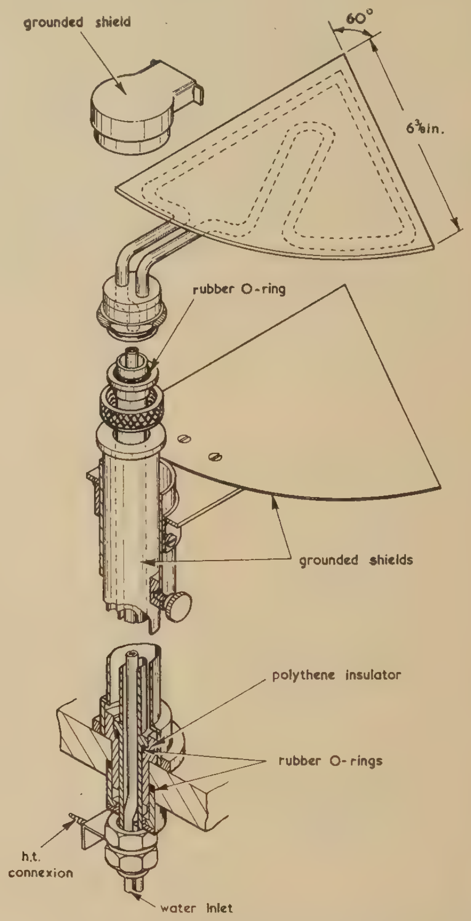

Fig. 2. Sputtering electrode showing earthed shields and water-cooling connexions

photometer capable of reading to an accuracy of ±0·1%
The reflectance of the resultant films was also measured wit
the same photometer as a function of wavelength using
series of Wratten filters. The glass specimens were gree
plate glass with a refractive index of 1·5. They were cleane
with a detergent and by vapour degreasing in *iso*-propy
alcohol vapour.

OPTICAL PROPERTIES

A simple anti-reflexion system for use on low index glasse
has been proposed by Osterberg, Kashdan and Pride.(4
The method consists in adjusting the optical thicknesses o
the layers so that their reflexion amplitudes sum to zero at
given wavelength. Sawaki and Kubota(5) have compare
the efficiency of this system with that of a single magnesiu
fluoride film and the "chromatic system" proposed b
Turner.(6) They found that the coating described b
Osterberg and others was more selective in its response a
different wavelengths than a single magnesium fluoride fil
or the chromatic system, but that it had the lowest luminanc
factor for white light. For this reason the system propose
by Osterberg and others has been used by the present authors

The refractive indices of sputtered bismuth oxide and aporated magnesium fluoride are about 2·45 and 1·38 spectively. From these values the optical thicknesses of e films in the two-layer anti-reflexion coating can be lculated for zero reflectance at a given wavelength. King d Lockhart(7) have given a general expression for the flectivity of a two-layer system and Cox, Hass and owntree(8) have calculated the optical thicknesses required r a range of film indices.

Using the materials discussed here the following values are otained for their optical thicknesses: 0·049 λ — bismuth xide and 0·33 λ — magnesium fluoride. There is also a cond solution for the optical thicknesses at which the flectance of the combined layers is zero at one wavelength, i.e. ·451 λ — bismuth oxide and 0·17 λ — magnesium fluoride; awaki and Kubota have shown that this solution has a high minance factor for white light.

For the purposes of controlling the optical thickness of e bismuth oxide layer it is necessary to know the reflectance the initial film before the magnesium fluoride is deposited. alculation shows that the reflectance of the bismuth oxide m should be about 8% so that the reflectance of the glass rface being coated must be raised by 4%.

Preparation of anti-reflexion coating. Experiments were itially made to determine the uniformity of the reflectance the sputtered bismuth oxide layer when measured across e diameter of the rotary holder. It was found that the oating on the central area of the 13 in. diameter holder ad a uniform reflectance of 7½% ± ½% within a 10 in. ameter circle. The fall in the reflectance at the edges of e rotary holder was due to a decrease in the film thickness. he molecules which are sputtered and diffuse through the as from the outer edges of the sector cathodes have a greater obability of capture on the chamber wall than the edge of e holder, because the chamber is nearer to the sector thodes in that region. It has been demonstrated elsewhere(9) that a condensing surface placed near the receiving ane influences the distribution of the sputtered film although does not optically shield the receiver from the cathode. Then the magnesium fluoride was deposited on the oxide-oated glass the reflectance was effectively reduced within 8 in. diameter zone on the work holder.

Given in Fig. 3 is the measured reflectance as a function wavelength in the visible region of a series of two-layer oatings with the bismuth oxide and magnesium fluoride ms deposited to obtain a minima reflectance at different avelengths. The reflectance of a single-layer magnesium uoride film has also been plotted for comparison purposes. he transmittance has been measured of a pile of plates ith coated and uncoated surfaces and the values obtained r up to six glasses agreed with those calculated using the flectance values given in Fig. 3. From this it was deduced at the absorption due to the coatings was negligible.

Critical adjustment of the wavelength of minimum reflecnce is made difficult when depositing the magnesium uoride because the reflectance measured by the photometer anges slowly with film thickness in the region of the inima. This tends to make the operator wait with the sult that the minima is displaced towards longer wavengths. Also visual monitoring, as generally used with ono-layers, has not proved an accurate form of control. he reflectance curve of the two-layer coating is not symetrical on either side of the minima as occurs with monoyers, but rises steeply on the lower wavelength side. Thus hen the minima is displaced towards the longer wavelength some 150 Å above 5300 Å, the reflectance of the coating for blue light is greater than that of the uncoated glass. When a number of surfaces are incorrectly coated the resultant transmitted light is strongly yellow tinted. Elaborate apparatus has been devised for accurately locating the maxima or minima reflectance of optical interference films used in multi-layer filters, but for controlling broad band anti-reflexion films the problem may be overcome by using a monitoring wavelength lower than the desired value and ceasing deposition when the photometer reading has passed through a minima and reached a specified value.

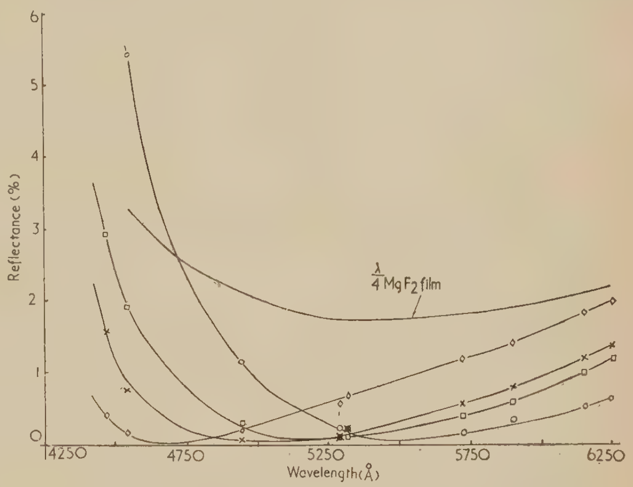

Fig. 3. Reflectance of two-layer anti-reflexion coating as a function of wavelength with the minima adjusted for different wavelengths. Curve of single-layer magnesium fluoride film included for comparison

With this method the authors have prepared films with a minima at $\lambda = 5300$ Å using a blue Wratten filter No. 50 which, combined with the photometer, had a maximum sensitivity at 4550 Å. The optical thickness and corresponding reflectance of the bismuth oxide film required at $\lambda = 4550$ Å to obtain the optimum value at 5300 Å is 0·058 λ and 9½% respectively.

Using the values for the reflectance at $\lambda = 4550$ Å of the two-layer anti-reflexion coatings given in Fig. 3, it is possible to draw a calibration curve relating the reflectance obtained at the monitoring wavelength after passing through a minima

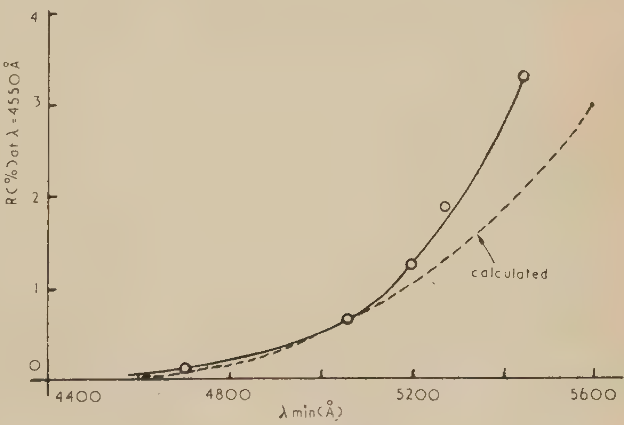

Fig. 4. Calibration curve for adjusting wavelength of reflectance minima in terms of reflectance at the monitoring wavelength ($\lambda = 4550$ Å)

to the wavelength of zero reflectance. The resultant curve is given in Fig. 4, together with the values obtained by approximate calculation using a vector diagram based on the Fresnel coefficients and neglecting multiple reflexions within the layers. The optical thickness of the bismuth oxide was adjusted at each specified wavelength to provide minima reflectance when the magnesium fluoride was deposited. This required varying the bismuth oxide reflectance, measured at the monitoring wavelength, from 8% to obtain a minima at 4550 Å to $9\frac{1}{2}$% to obtain a minima at 5300 Å.

WEAR RESISTANCE

The wear resistance of the two-layer films has been determined by abrading their surfaces using a reciprocating machine of the type described by Holland and Van Dam(10) for testing magnesium fluoride films. The abrasive head of the machine was fitted with a rubber impregnated with emery powder grade 302 supplied by the British Scientific Instrument Research Association. The test specimen was mounted on a support which rotated through one revolution for every three single strokes of the abrading head, so that the rubber traced out a series of flat spirals on the film. The rubber was $\frac{1}{4}$ in. in diameter and under a load of 112 lb/in^2. The length of the abrasive stroke was $\frac{3}{4}$ in. so that the overall diameter D of the abraded area was 1 in. The abrasion of the coating gradually removed the deposit from a central region, which could be discerned by the reflexion of the uncoated glass. A figure of merit for the wear resistance of a film could be obtained by measuring the diameter d of the removed coating and expressing its area as a percentage of the total area abraded, i.e. $w = (d/D)^2 \times 100\%$.

Average values of w obtained in each case for three samples of two-layer coatings prepared at different base temperatures and tested at 200 and 1000 single strokes of the abrading head are given in the table. Also included in brackets in the table are values of w for hard $\lambda/4$-films of magnesium fluoride deposited on glass which has been cleaned in a glow discharge and baked at 300° C.

The glass specimens were not cleaned in a glow dischar before sputtering the bismuth oxide as is essential for pr ducing adherent single-layer magnesium fluoride films, b their wear resistance is of a high order. This is because the cleaning action of the glow discharge used for sputterin and the high adherence of the bismuth oxide to the glass bas

Wear resistance of two-layer anti-reflexion coatings wi comparative values for magnesium fluoride films given brackets

No. of rubs	*w* 20° C	*w* 200° C	*w* 250° C
200	6 (15)	3	3 (5)
1000	34	15	5 (6)

ACKNOWLEDGEMENTS

Acknowledgements are made to Mr. A. S. D. Barret Technical Director of Edwards High Vacuum Ltd., f permission to publish this account.

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Continuous reading balance for oxidation studies

By E. Dempsey, B.Sc., Ph.D.,* Atomic Weapons Research Establishment, Aldermaston, Berkshire

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An instrument designed for studying the oxidation behaviour of a toxic radioactive metal is described. The mode of suspension, consisting of a crossed spring arrangement, while being very robust, permits the detection of mass changes of 50–100 μg. in an initial specimen mass of 1–2 g.

To study the oxidation characteristics of certain radioactive metals (notably plutonium), it was considered that the design of suitable apparatus should take account of the following features:

(1) Since it is known that the oxidation rate of plutonium is, in general, high, a continuous reading gravimetric method seemed suitable.
(2) Since only small specimens of material would be available, the balance sensitivity had to be reasonably good.
(3) To maintain accuracy in the results, and for ease of calibration, the balance response to weight increase ha to be linear if possible.
(4) In view of the fact that all work on plutonium i carried out in glove boxes,(1) making manipulation c apparatus somewhat awkward, the balance had to b robust and, as a precaution against damage, parts ha to be simple to make and replace.

Taking as a guide to the required sensitivity a mass of 1 of plutonium oxidizing completely to plutonium dioxide, th balance had to be capable of giving a reasonable number readings over a small part of the range 1–1·134 g.

DESCRIPTION OF THE BALANCE

Eventually the instrument shown in Fig. 1 was constructed This is in fact the second version of the instrument. Th st model is shown in Fig. 6 of Ref. 2; its sensitivity was nly half that of the instrument described below.

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The beam of the balance is a bar of duralumin about 8 in. ng, 0·25 in. high and 0·125 in. thick, cut away and drilled ut along its length to decrease its weight. At one end, at ght angles to its length, the beam carries a duralumin shaft nning in jewelled bearings (see inset to Fig. 1); the shaft tapered towards its centre in order to centre the hook of e crucible suspension. In the original model of the balance e vertical crucible suspension terminated in a horizontal ross-bar which lay in a groove cut in the balance beam. his arrangement was replaced by the present one after a ertain amount of trouble had been experienced in some of e slower oxidation runs on plutonium. It is thought that is was due to the cross-bar sticking in the groove and then, s the beam tilted downwards with increasing mass in the rucible, suddenly being released and dropping back in the roove. This resulted from time to time in slight jumps owards higher mass readings in the otherwise smooth plots f mass increase against time. In faster runs the motion of e cross-bar in the groove must have been more or less ontinuous, and the effect was presumably absorbed in the eflexion due to true mass increase. It is assumed that the near calibration graphs of the original instrument included is effect. This is borne out by results obtained on copper hich agree with the results of other investigations. (It is oped to publish these in due course.)

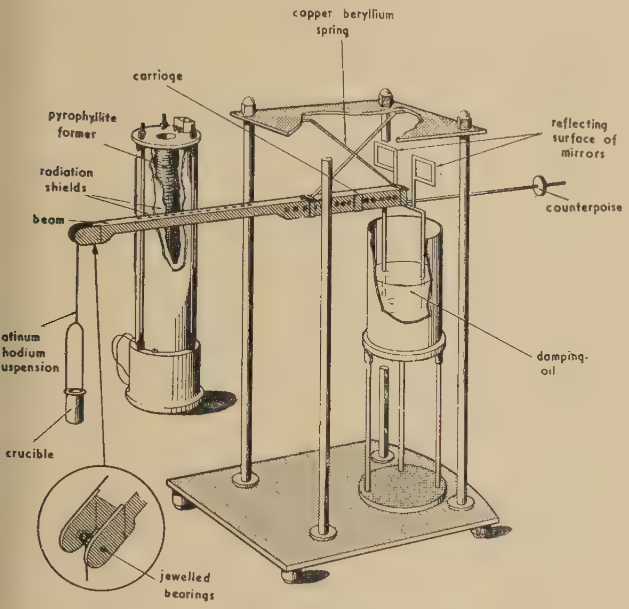

Fig. 1. Diagram of the balance and furnace

The crucible suspension is constructed from platinum–odium alloy wire (0·02 in. diameter) and is about 6 in. ong. One end is bent into a hook and the other end terinates in an inverted U to which is welded a horizontal ng of wire which supports the crucible. Platinum–rhodium as chosen for its oxidation resistance, strength and lack of rromagnetism; using a steel or nickel suspension, a relavely large deflexion of the beam occurred on switching on e furnace (which is inductively wound).

The crucibles are of pyrophyllite and are about 0·75 in. ong, 0·45 in. diameter and 1·5 g in weight. Each has a arrow lip which rests on the ring of the crucible suspension. In practice a specimen is not placed in the crucible but is suspended just inside the crucible mouth by a fine platinum wire tied to the crucible suspension wire. This ensures that the oxidizing specimen receives an adequate supply of oxygen or air, and at the same time ensures that any oxide which falls from the specimen will be caught in the crucible.

The beam of the balance fits tightly into three brass stirrups brazed at equal intervals to the underside of a brass plate 2·6 in. long and 0·25 in. wide; this is referred to in Fig. 1 as the carriage. The plate of the carriage widens to 0·5 in. over the last 0·3 in. at each end where the suspension springs are clamped. Brazed to the stirrup holding the end of the beam is a system of two brass damping rods dipping into silicone oil, and a brass counterpoise rod threaded along its length to carry a heavy brass bob. To the damping rods are fixed two brass frames holding plane mirrors: these are about 0·5 in. square. The whole structure on the end stirrup is constructed so as to be symmetrical with respect to a longitudinal vertical plane down the centre of the balance beam. By placing the damping and viewing systems at the counterpoise end of the carriage these structures help to reduce the necessary counterpoise mass; in this way the overall weight of the balance is kept to a minimum. Two mirrors are used to preserve symmetry and as a precaution against one of them being damaged once the instrument has been placed in a glove-box.

The balance suspension consists of two flat strips of copper–beryllium spring(3) each 3·8 in. long, about 0·08 in. wide and 0·005 in. thick. The last half-inch of each end is bent sharply at an angle of 135° to the main part to provide a means of clamping the springs. Each spring is clamped at one end to the carriage and at the other end to a heavy brass stand in such a way that the springs are at right angles to each other, and are separated at the cross-over point by about 0·2 in. The clamps are short straps of brass which lie across the ends of the springs just before the angles, and are held to the carriage and stand by small screws.

Deflexions of the beam of the balance corresponding to mass increases at the crucible are observed using one of the mirrors on the carriage to reflect an image of a millimetre scale into a viewing telescope adjacent to the scale. At a distance of about 2 m between the mirror and the scale an increase in mass of 0·1 g in the crucible gives a change in position of the telescope cross wire of about 200 mm on the scale. Since a change of about 0·1 mm in the position of the telescope cross-wire may be estimated, the minimum change in mass which can be detected with the instrument under the present arrangements is limited to 0·05 mg.

DESCRIPTION OF THE FURNACE

The furnace consists of a pyrophyllite former 6 in. long and 0·75 in. inside diameter, threaded to carry the Nichrome furnace winding; the bottom end is closed by a heavy brass block. Two polished stainless steel radiation shields help to increase the furnace efficiency. In order to obtain a fairly uniform temperature zone in the centre of the furnace, the number of windings per unit length was increased towards the ends of the former and the brass block was cut away from the inside. Eventually the furnace was found to have a region 1 in. long near its centre in which the total temperature variation was within ±1° C at any equilibrium temperature in the range used.

The furnace temperature is varied by means of a Variac transformer fed from a constant voltage transformer to minimize mains current fluctuations in the furnace windings.

The specimen temperature is recorded continuously* on a millivolt recorder *via* a thermocouple which passes up the outside of the furnace former and through a hole at the centre of the former to the centre of the furnace. The thermocouple junction is placed as near as possible to the oxidizing specimen without actually being in contact with it. In a test using a thermocouple at the centre of the furnace, the overall temperature variation recorded during 15 h at 400° C was within ±1·5° C and most of the more serious temperature excursions could be associated with obvious thermal disturbances (opening of the laboratory door or windows, for instance).

PERFORMANCE OF BALANCE

Investigation of the constancy of an equilibrium reading of the balance has shown this to be very good over a period of a day or more. Even on disturbing the instrument fairly roughly the equilibrium reading does not usually alter by more than a maximum of about 0·25 mm (about 10^{-4} g). Removing and rehanging the crucible suspension may produce changes of the same magnitude in the equilibrium reading.

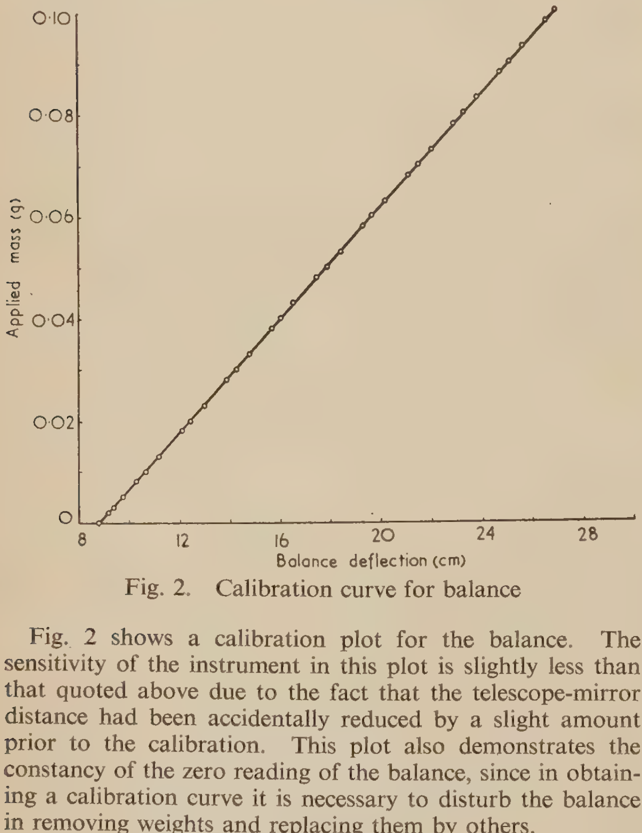

Fig. 2. Calibration curve for balance

Fig. 2 shows a calibration plot for the balance. The sensitivity of the instrument in this plot is slightly less than that quoted above due to the fact that the telescope-mirror distance had been accidentally reduced by a slight amount prior to the calibration. This plot also demonstrates the constancy of the zero reading of the balance, since in obtaining a calibration curve it is necessary to disturb the balance in removing weights and replacing them by others.

Fig. 3(*a*) shows the result of an actual oxidation run on a copper specimen in air at a temperature in the region of 530° C. The specimen was cut from copper foil 0·003 in. thick and measured about 3 × 1·125 in.; for the run it was rolled into a loose coil after cleaning and was placed on the lip of the crucible. The plot illustrates how well the experimental points lie to a smooth curve. The maximum deviation of any point from the curve corresponds to a mass of about 10^{-4} g.

Fig. 3(*b*) demonstrates the parabolic nature of the oxidati
process for copper; in this graph the square of the balan
deflexion in the previous graph is plotted against time. T
initial deviation from the straight line may be ignored sin
plots of this nature frequently show such a deviation(4); it
a characteristic of the oxidation of copper.

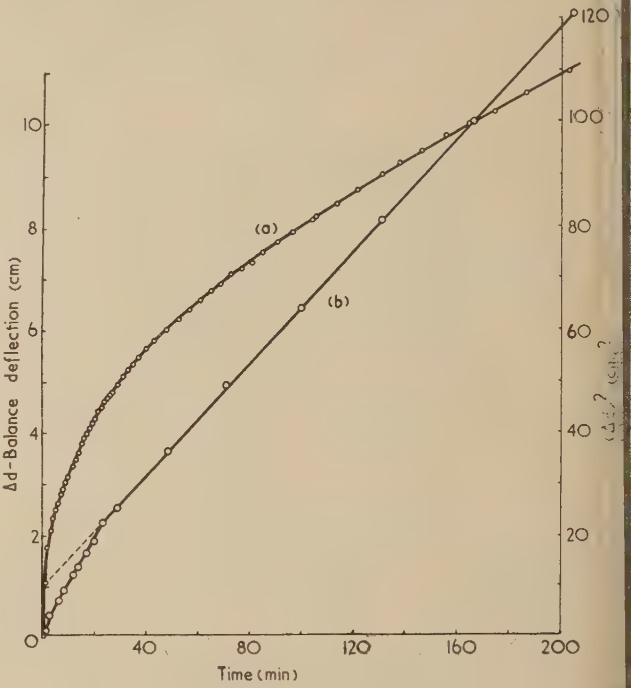

Fig. 3. Oxidation of copper foil at ∼530° C

CONCLUSION

The instrument as described above was designed fo
oxidation work involving relatively large changes in mass i
the oxidizing specimen; it was felt that the limit of th
apparatus had been reached in one run involving the oxidatio
of a specimen which changed in mass by a total of abou
0·001 g over two hours. However, it should be a fairl
simple matter to increase the sensitivity of the instrument
this may be achieved by using thinner and longer springs
and at the same time reducing the total mass carried by th
springs, by increasing the effective mirror-telescope distance
or by using a more powerful telescope in conjunction with a
scale ruled to fractions of a millimetre. One of the mai
advantages of the instrument lies in the fact that readings
may be taken at very short intervals so that it may be used
in runs of short duration, provided the specimen can be got
to its equilibrium temperature sufficiently quickly. It also
has the advantage that quite heavy specimens may be used
although for specimen masses above about 2–3 g the increase
in dead weight supported by the spring system will result in
some loss in sensitivity. The instrument is ideally suited to
glove-box work in that (*a*) the apparatus is easily set up and
calibrated, (*b*) it is very robust and requires little adjustment
over long periods, (*c*) once a run has been begun it is not
necessary to handle the apparatus till the run has been
completed.

ACKNOWLEDGEMENTS

I should like to thank Dr. A. E. Kay for drawing my attention to the paper of Ref. 4, and Mr. R. F. Powell for obtaining the results shown in Figs. 2 and 3.

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* This is an improvement on the method used previously(2) of measuring the furnace temperature before and after a run.

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Thermostat suitable for controlling air temperature, particularly in biological research

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Some of the features essential to the control of air temperature in small and unlagged containers are outlined, and apparatus is described which will control the temperature in such a container to ±1/50° C. A system of continuous proportional control is used, based on a two-stage directly coupled amplifier whose input is dependent on the resistance of a thermistor, and whose output is fed directly to the heating element. Incorporation of variable positive feedback makes it possible to attain high sensitivity, or alternatively to use the equipment without modification as a switching thermostat and electronic relay for large power loads. A description is also included of a temperature-measuring system based on a thermistor, which will display the air temperature to ±1/50° C.

e measurement and control of air temperatures in observan boxes of a few litres capacity is a common requirement biological research. However, owing to the low thermal pacity of air, the difficulty of providing both insulation d adequate observation facilities and the differential erent in the typical switching thermostat, stability and sonably fine control of temperature are very difficult to tain in such systems. The equipment described here ercomes these problems by using a continuously variable urce of heat, the output of which is controlled by a rmistor. A thermometer is also incorporated, of which temperature-sensitive element is likewise a thermistor. wever, by a simple adjustment of one control, the device n be used without modification to control large heat loads the conventional manner, and offers some advantages in s application. The whole has been designed as a self-contained unit operating from an a.c. mains supply, crudely rectified by germanium rectifiers, and, apart from the heater element itself, uses standard components throughout.

MEASUREMENT

The advantages of thermistors as temperature-sensitive elements in thermometry are too well known to need repetition here. Provided that they are individually calibrated, their stability is largely determined by their temperature experience; over the range of temperatures likely to interest biologists, their characteristics are not likely to vary significantly. Type F/1512/300 Stantel thermistors (by Standard Telephones and Cables Ltd.) are used; the resistance of the measuring element is compared (see Fig. 1) with a selected reference resistance (S_1b) by means of a twin-triode cathode follower. The power dissipation, and hence the self-heating,

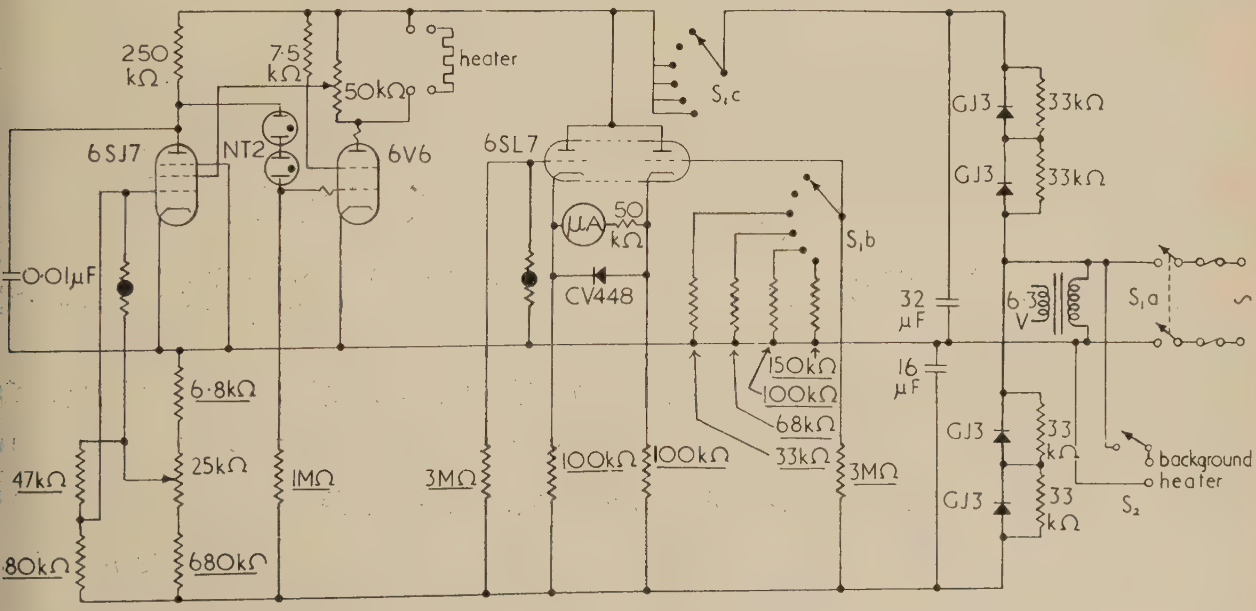

Fig. 1. Circuit diagram of the unit

of the thermistor is limited by feeding it through a 3 MΩ resistor from the negative line. The reference resistor is similarly fed, and the voltage difference at the two grids is displayed by a meter across the cathodes. A 50 μA meter, in series with a 50 kΩ resistor, is suitable for this purpose. Since the circuit is symmetrical, and to a great extent balanced, any fluctuation in mains voltage is effectively minimized. In the particular model shown in Fig. 1, four temperature ranges can be selected by the switch S_1, covering 15–20° C, 20–30° C, 30–50° C and 50–100° C, each being presented over the full meter range. It may be necessary to pad the reference resistors empirically to ensure that the ranges just overlap; high stability resistors are advisable for the main components. On the lowest range, temperatures can be read to 1/50° C on a 3 in. meter, with a halving of reading accuracy on each successive range. In order to protect the meter against overload, the switching system is arranged such that the operation of the master switch (S_1) brings the equipment first on to its highest temperature range. If the temperature is below 50° C, so that a reverse voltage is applied across the meter, the small germanium rectifier in parallel shunts it. Since such a rectifier has a temperature-dependent back resistance, it should be mounted away from heat-emitting components.

Owing to the low thermal capacity of the thermistor, temperature fluctuations in air are followed rapidly, and to the same order of accuracy as that to which control may be obtained.

CONTROL

When a conventional switching thermostat is used to control the temperature of air or other materials of low specific heat, comparatively large cyclical temperature fluctuations are normally obtained. Among the contributory factors are: (*a*) the heater has a large thermal capacity compared with the air, and continues to heat the air after it has been switched off; (*b*) there is, in general, a difference between the temperature of the air and that of the thermostat element, so that the air temperature may have dropped appreciably before bringing the element down to re-energization temperature; and (*c*) interaction of cyclical heater operation and forced air circulation may give rise to substantial "hunting." While the use of the thermistor with its low thermal capacity reduces factor (*b*) to negligible proportions, the difficulties of intermittent heating remain. However, the resistance-temperature characteristic of a thermistor is very suitable for controlling a continuously variable source of heat. For small volumes of air the output of a typical power tetrode is quite sufficient to raise the temperature by several degrees, and if the heating element is made the anode load of such a valve the basis of proportional control, with all its advantages, is achieved.

The heater (Fig. 2) which is designed to have the lowest possible thermal capacity [see factor (*a*) above] consists of a length of 42 s.w.g. Nichrome wire, wound on a flat mica frame; it has a resistance of 2 kΩ. It is mounted in an open-ended tube with a magnetically driven fan below it to maintain air circulation through it. By comparison, a similarly blown 5 W vitreous resistor gives much too large a time lag between power input and heat dissipation. The heater is fed from a two-stage directly coupled amplifier (Fig. 1) with the controlling thermistor in the grid circuit of the first pentode. Heat dissipation in this thermistor is again minimized by feeding it through a high resistance, and selection of the control temperature is achieved by backing-off the thermistor from a suitably arranged potentiometer. Two miniature neon tubes are used for interstage coupling. The gain of t amplifier is then increased by applying positive feedba from a potentiometer in parallel with the anode load of t output stage, back to the screen of the first pentode. Over negative feedback, to maintain stability, comes of cou from the thermal link between the heater and the thermisto For the initial adjustment of sensitivity, a milliammeter placed in the anode circuit of the tetrode, and the amou of positive feedback is adjusted to give the maximu excursion of output current for minimal movement of t temperature-setting control.

A further working range can be obtained by bringing background heater into operation (S_2). Alternatively, larger valve may be substituted for the type 6V6; a u using a type 12E1, capable of delivering 30 W into t heater, has been constructed.

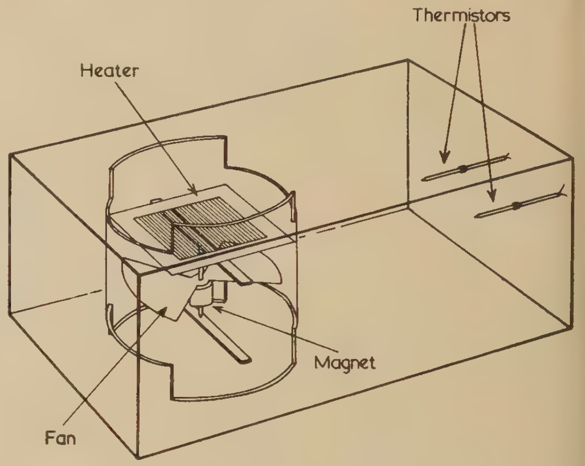

Fig. 2. Arrangement of heater and fan

PERFORMANCE

The performance given below was obtained using a otherwise uninsulated polystyrene food-box, which hel about two litres of air, stirred only by the fan under th heater—a four-blade propellor fan, $1\frac{1}{2}$ in. diameter runnin at 240 rev/min. On the lower range, temperatures wer controlled over the range 20–35° C to better than ±1/50° with the ambient temperature at around 15° C. At 25° internal temperature, the recorded change was less tha 1/20° C for an ambient excursion of 10° C. On the highe temperature range, control up to 55° C was obtained, wit accuracy better than ±1/20° C. In the effective workin space, i.e. within a few centimetres of the thermistors, th uniformity of temperature is of the same order as the accurac of control. Measurements of heating current show that is without cyclical variation once a new temperature settin has been obtained, provided that the air stirring is efficien care must, however, be exercised in placing other objects i the box so that they do not interfere with the thermal lin between the heater and the thermistor. The behaviour c the anode current is an excellent indication for this. Mov ment to a new higher temperature takes place very rapidly since the tetrode is operating "hard on" during the change The rate of downward movement will, of course, be governe by the insulation of the box.

CONTROL OF LARGE HEAT LOADS

If the amount of positive feedback is increased beyon the optimal for proportional control of the output, th nplifier will be turned from "hard on" to "hard off" by ry small changes of temperature; a controllable amount hysteresis therefore appears. The output can then nveniently be used to operate a large conventional ay (e.g. 100 V, 40 mA) and thus to control quite rge thermal loads. Although the cyclical temperature ictuations in the system will be larger than with propor-onal control, the sensitivity of the thermistor under these rcumstances gives the system considerable advantages er typical thermostatic devices for the regulation of air mperatures.

THE MAGNETIC DRIVE TO THE FAN

The fan spindle carries a small "button" magnet; about 2 in. below it is a $1\frac{1}{2}$ in. long bar magnet rotated by an a.c. motor. If the motor is merely switched on, it comes up to speed so quickly that the fan does not "pull in," but remains stationary. A thermistor (Brimistor type CZ2, by Standard Telephones and Cables Ltd.) is therefore included in series with the motor. The current through the motor rises slowly as the thermistor heats up, and the motor speed increases gradually. The fan rotation then remains synchronous with that of the motor throughout the running-up period.

Electron bombardment apparatus for vacuum evaporation

By J. C. Kelly, Ph.D., Grad.Inst.P.,* Physics Research Laboratory, University of Reading

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Simple experimental arrangements are described for the evaporation of tantalum and zirconium from a pendant drop, maintained molten by electron bombardment. The method is clearly of general application and has advantages over existing techniques. Since there is no boat or container there is no possibility of solution of the boat material and consequent contamination of the evaporant. The material to be evaporated is used in wire or rod form; these may be very easily interchanged.

lectron bombardment has been used for floating zone elting of metals by Calverley, Davies and Lever.(1,2) These uthors have noted that for metals with a high vapour ressure when molten, the viewing ports become covered with ms of the metal being zoned. This suggests that electron ombardment may be useful in evaporating metals which, ecause they alloy with conventional evaporation heaters or ecause of their high melting point, are normally difficult to aporate.

The apparatus described here was developed to prepare aporated films of zirconium (m.p. 2100° C) and tantalum n.p. 2800° C) but may be used for many metals. The initial pparatus was made in glass so that the drop behaviour ould be closely studied. A rod of the material to be aporated is suspended vertically (Fig. 1) from a bellows quipped with three screw adjustments. This gives sufficient ertical and lateral movement without the need to run a ioving shaft into the vacuum system. The rod forms the node of the bombardment system. The bellows is O-ring-aled to a ground glass flange on the glass vacuum system hich is fabricated from a two-litre Pyrex flask. The anode ods are threaded for a centimetre and screwed into a holder n the inside of the dome of the bellows. A change from ne metal evaporation to another can quickly be made by removing the bellows assembly and screwing in the anode rod of the new material.

The cathode assembly consists of a single loop of 0·5 mm tungsten wire fastened across the ends of threaded rods with steel nuts and washers. Two focusing plates are mounted on one of the rods, half a centimetre above and below the cathode loop. In Fig. 1 the lower plate has been removed to expose the cathode loop. The specimen holder can conveniently be attached to one of the cathode leads. The plates above and below the molten drop are arranged so that the cathode loop can be seen by neither the anode drop nor the specimens to be coated. There is thus no possibility of contamination of the specimen, either by direct evaporation from cathode to specimen or by cathode material re-evaporated from the anode.

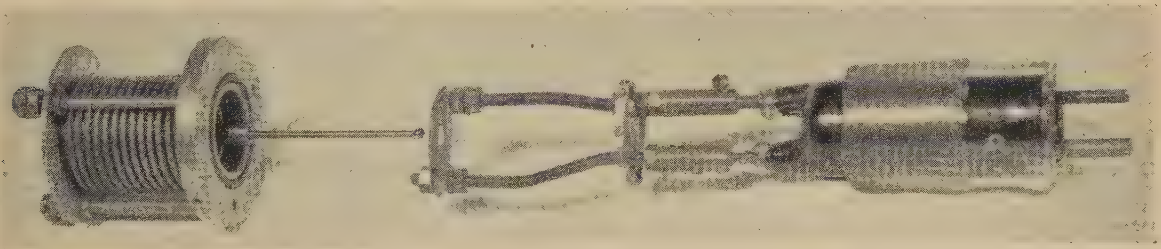

Fig. 1. Electron bombardment vacuum evaporation apparatus. Lower focusing plate removed to expose cathode loop

The cathode is earthed to avoid insulation difficulties with the low tension high current supply for the cathode heater. The bombardment voltage was obtained from an unsmoothed half-wave rectifier capable of delivering 3 kV at 600 mA and Variac controlled. The only protective devices found necessary were fuses in the primary of the h.t. transformer and the d.c. line. A series resistor was used to limit the bombardment current in the event of accidental contact between anode and cathode or sudden out-gassing of the molten specimen.

As the amount of molten metal involved is comparatively small, no special emission control devices were necessary.(1) The drop could readily be controlled in size and temperature by adjustment of the cathode heater current. If the drop temperature is raised above a certain level, oscillations of the drop of the type shown in Fig. 2 occur. This increases the danger of the anode rod welding itself to the cathode plate. Successful evaporations in a reasonable time are, however, possible with the drop below the oscillation temperature. It is desirable to melt the drop in a preliminary run before exposing the specimens to be coated, as on first melting, some metals, e.g. tantalum, scatter small droplets of metal about the system, particularly if the drop is allowed oscillate. Further, the heat of this initial run outgasses t system and reduces the danger of contamination.

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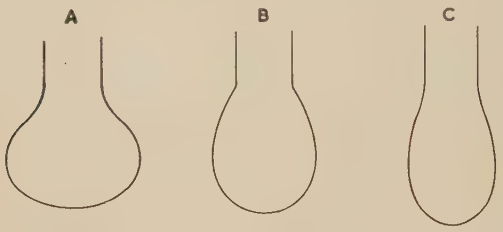

Fig. 2. Mode of oscillation of pendant drop of molten metal under high bombardment currents—
A—B—C—B—A—B—

The power required for evaporation is not large. Evapor tion from a 3 mm zirconium rod requires only 10 mA 2200 V, and from a 2·5 mm tantalum rod only 80 mA 2200 V. This could be further reduced by the use of mo elaborate focusing methods. The aim in the present apparat has been to keep the electrode structure as simple and ope as possible to give maximum coverage of the evaporatin metal and to facilitate visual observation of the molten dro

ACKNOWLEDGEMENTS

The author is indebted to Mr. A. Calverley for discussion and to the Director and to Dr. H. M. Finniston of the Atomi Energy Research Establishment for financial support durin the course of this work.

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Recording optical lever

By R. V. Jones, F.Inst.P., and J. C. S. Richards, Natural Philosophy Department, University of Aberdeen

[*Paper first received* 30 *July, and in final form* 26 *August*, 1958]

A small optical lever is described which can detect a change of 10^{-10} rad in orientation of a 2 mm^2 mirror, with a response time of about 0·25 s. A differential cadmium selenide photocell is used with a standard optical grid technique to detect the displacement of the reflected light beam from a 4 V 3·2 W lamp. Transistors are used to stabilize the lamp current and to amplify the signals for a pen recorder. "Noise" arising from convection currents in the light beam and from the photocells appears not to exceed greatly the photon fluctuations in the light beam. Records illustrate the performance of the lever and amplifier in detecting changes in dimension of a crystal of a few times 10^{-10} cm and changes in refractive index of a gas by a few times 10^{-9}. The system has also been applied to an infra-red detector using the linear expansion of a metallic strip, where the limit for a 5 × 0·2 mm strip is about 10^{-11} W for a 1 c/s bandwidth. For this purpose the signal can be differentiated with respect to time, and velocities of down to 30 μ/annum can be observed. It appears that a displacement of 10^{-12} cm could be detected.

INTRODUCTION

The use of cadmium selenide as a photoconductive material has led to the production of small sensitive photocells (e.g. by Schwarz(1)) and such cells have been applied by Thulin(2) to optical levers. The present paper describes work at Aberdeen with Hilger-Schwarz and similar cells which has improved the sensitivity of optical levers by more than an order of magnitude over the best previously described.(3) This previous performance had been obtained by using barrier layer or vacuum photocells with a 48 W projection lamp as the light source, giving a limiting useful sensitivity of about 10^{-9} rad for 1 s response time. Apart from the brightness of the source, the main factors in reaching this sensitivity were the attainment of high mechanical and thermal stability, and the elimination of convection currents in the optical path. The same factors hold in the present design, but the problems have been simplified by the small size and high sensitivity of the photocells. A 4 V 3·2 W miner's cap lamp bulb now suffices as the source, and the low heat dissipation of this lamp combined with the general reduction in size of the optical lever system has facilitated the design of a compact amplifier which can detect changes in angle of about 10^{-10} rad in the orientation of a 2 mm mirror with a response time of about 0·25 s.

The first co-author has been responsible for the optical and mechanical details, and the second for the electronics.

OPTICAL DESIGN

The optical design follows that of previous amplifiers(3) with modifications to concentrate the reflected light from the mirror on to the small area (twice 5 × 1 mm) of the differential photocell. The system is shown in Fig. 1, and the construction in Fig. 2.

The source S is a miner's cap lamp bulb rated at 3·2 W at 4 V, krypton-filled, type MES 408 K; these lamps last for months when continuously run. They give sufficient light to operate the photocells, without developing so much heat as to require any special cooling arrangements. An image of S is focused by the condenser lens L_1 (which consists of two plano-convex lenses each of 70 mm focal length and 32 mm diameter, separated by 5 mm) on to the mirror M, which can be as small as 1 × 1 mm, but is preferably of twice to four nes this area. M is attached to the system whose rotation to be measured. The light reflected from M diverges until reaches L_2; this lens is a condenser exactly similar to L_1, d it focuses an image of M, and therefore of S, on the rface of the double photocell X_1X_2 (type FT435 by Hilger d Watts Ltd.). Interposed between L_1 and M and L_2 is a bsidiary system consisting of a lens L_3 (an achromat of 0 mm focal length and 25 mm in diameter) near the mirror , and two grids G_1 and G_2. G_1 is illuminated by converging ht from the condenser L_1, and is so situated that the rays verging from any point on G_1 are made parallel by L_3; er reflexion from M these rays return through L_3 to be cused in the plane of G_2. Thus an illuminated image of appears in the plane of G_2; this is the standard auto-llimating position, and results in a distortion-free image at it magnification. If G_1 and G_2 are replicas, G_2 will stop pass the light from G_1 depending on their relative positions insverse to the light path. G_2 is split into two halves, parated by the width of a bar in the grids, so that when the ht half of G_2 passes the light from G_1, the left half of G_2 ps the light from G_1. Viewed from L_2, the effect is that a vertically divided field, in which the halves go alternately ack and white in anti-phase as the mirror M is rotated. narrow angled prism P, conveniently made of Perspex, is aced behind one half of L_2 with its vertex horizontal, to vert the light from this half sufficiently downwards to fall a focused image of S on the lower half X_2 of the photocell. ght passing through the other half of G_2 and L_2 is undiverted, d forms a focused image of S on the upper half X_1 of the otocell. The arrangement thus results in an image of S ling on each half of the photocell. As M rotates, both ages maintain their positions but their intensities change, e to the varying degrees of overlap between the image of and the two halves of G_2. The system is operated with out a 50% overlap on each half, giving equally intense ages on X_1X_2. A slight rotation of M causes one image brighten, and the other to darken; the bridge circuit ntaining X_1 and X_2 then registers an out-of-balance rrent.

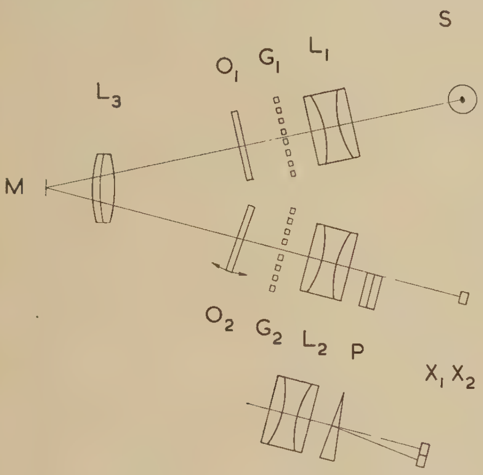

Fig. 1. Schematic plan of optical lever

Components L_2, P, X_1X_2 are shown also in elevation.

In order to adjust the transverse position of the image of , an optical micrometer plate O_2 is placed in front of G_2. is plate is of plane parallel glass about 2 mm thick, and is tated about a vertical axis by a mechanical micrometer; tation of O_2 through a few degrees causes sufficient transverse shift of the image of G_1 to cover the whole range of a grid spacing. Since the interposition of O_2 somewhat upsets the symmetry of the optical system, a fixed plate of similar thickness, O_1, is placed at the corresponding position in the incident beam. This reduces any loss of image quality due to O_2.

The grid spacings selected depend on the application; finer grids give greater effective sensitivity at the expense of maximum measurable rotation. A limit to the fineness of the grid that can be used is set by the aberrations of the system and by the diffraction at M; generally between 5 and 70 lines/cm are suitable. The system will measure linearly rotations up to about one quarter of the angle subtended by one grid bar and space at the focal length of L_3. The grids can be made in several ways; the method employed here has been to make a wire grid, and then to take replicas by evaporating aluminium through it on to glass.

The illumination on the photocell surfaces, when a mirror of 2 mm^2 area is used, is some hundreds of lux. This is sufficient to ensure satisfactory operation of the photocells.

CONSTRUCTION

The construction is outlined in Fig. 2. It is sufficiently substantial to avoid any danger of components shifting undesirably. The baseplate is of mild steel, $\frac{1}{2}$ in. thick. The lens holders are also of mild steel; slotted holes in their bases allow sufficient movement for approximate focusing. A screw focusing mount for lens L_3 gives a fine adjustment of the image of G_1 on G_2. The glass plate O_1 and the grids G_1 and G_2 are gripped in slotted holders (of brass or steel) by their lower edges, and screwed to the baseplate. The optical micrometer plate O_2 is mounted on a cross-strip pivot (out of sight beneath the baseplate) which is rotated by the micrometer visible at the side of the baseplate. The source S and the photocells X_1X_2 are mounted as shown, appropriate adjustments being allowed by slotted holes for the fixing screws. The supply leads are soldered directly to the lamp so as to avoid any danger of variable contact.

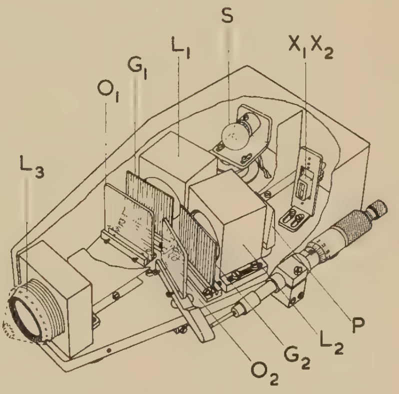

Fig. 2. Construction of optical lever

Overall length of baseplate = 20 cm.

An exterior cover (shown broken) is provided, along with a centrally placed screen, to reduce the circulating volumes for convection currents. This screen and the inside of the cover are painted black to reduce the amount of scattered light reaching the photocells; they also improve the cooling of the lamp by radiation.(4) For the greatest suppression of convection currents, it may pay to seal the gaps between the lens holders and the cover and screen with paper baffles.

The conical Perspex nosecap (shown dotted) on the front of the lens L_3, and extending between it and whatever screen surrounds the mirror M, is particularly important. Without the nosecap, convection currents and dust particles drifting across the gap will cause much disturbance. The distance between L_3 and M should desirably be as small as possible, to minimize aberrations, but the system is designed for this distance (which plays the part of the "working distance" in a microscope) to be as much as 25 mm, so that the lever will work satisfactorily when the mirror is part of an instrument which does not permit a closer approach, as for example when it is in a vacuum jacket. There is little point in giving exact dimensions of the components in the lever, since the simplest procedure in constructing a similar instrument elsewhere would be to pick lenses from stock which are approximately of the dimensions given in this paper, and then ascertain the most suitable layout on an optical bench.

The whole instrument is mounted on three adjustable screw feet, so that it may be suitably levelled with respect to the mirror. The assembly is surrounded by a Perspex case to reduce the effect of external temperature variations and draughts, and is run continuously to keep the internal temperature steady.

ELECTRICAL ARRANGEMENTS

The twin photocell is connected with two load resistors in a Wheatstone bridge network. For purposes of initial design each half of the illuminated photocell (type FT435 by Hilger and Watts Ltd.) may be assumed to have a resistance of 20kΩ; the actual resistance will, of course, vary with individual photocells and optical arrangements. Thulin(2) has shown that the sensitivity of such a bridge may be made independent of the lamp brightness by feeding the bridge from a constant current rather than a constant voltage source. However, if maximum zero stability is to be attained in the present arrangement it is necessary to keep the lamp voltage as constant as possible (within $\pm 0{\cdot}1\%$ say) in ord to eliminate thermal effects, and Thulin's technique th offers no great advantage. If the apparatus is used on occasionally, secondary batteries may be used to supply t lamp and, since the current through each half of the phot cell is limited at 2 to 3 mA by considerations of therm dissipation, dry Leclanché cells may be used to feed t bridge. The out-of-balance signal from the bridge can observed on a galvanometer; assuming that the galvanomet resistance is appreciably less than the bridge resistances, sensitivity of 10^{-8}–10^{-9} A/mm is adequate. However, f most purposes it is more convenient to apply the output fro the bridge to a pen recorder *via* an electronic amplifier, an to derive all power supplies from the a.c. mains.

Because of the high sensitivity of the photocells, it is n difficult to design a suitable amplifier. Even under the be conditions noise and short term drifts in the optical lev are likely to give an output from the bridge of more th 100 μV.

Two different electronic amplifiers and lamp power suppli have been used. In both amplifiers a transistor input sta is employed, since the output impedance of the bridge comparatively low. The second and output stages of th first amplifier use thermionic valves, and the power supp for the lamp is the same as that described by Richards apart from the obvious modifications to reduce the out from 6·3 V to 4 V. Although this arrangement perform satisfactorily, a more compact and elegant apparatus can made if transistors only are used.

The complete circuit of the second electronic amplifier given in Fig. 3. The first stage consists of two transisto in a push-pull configuration with a large common emitt resistance; this type of balanced stage reduces the effects temperature and voltage changes common to both transistor provided the transistors have reasonably similar chara teristics. Temperature differences between the transisto are minimized by fitting them in holes drilled in an aluminiu

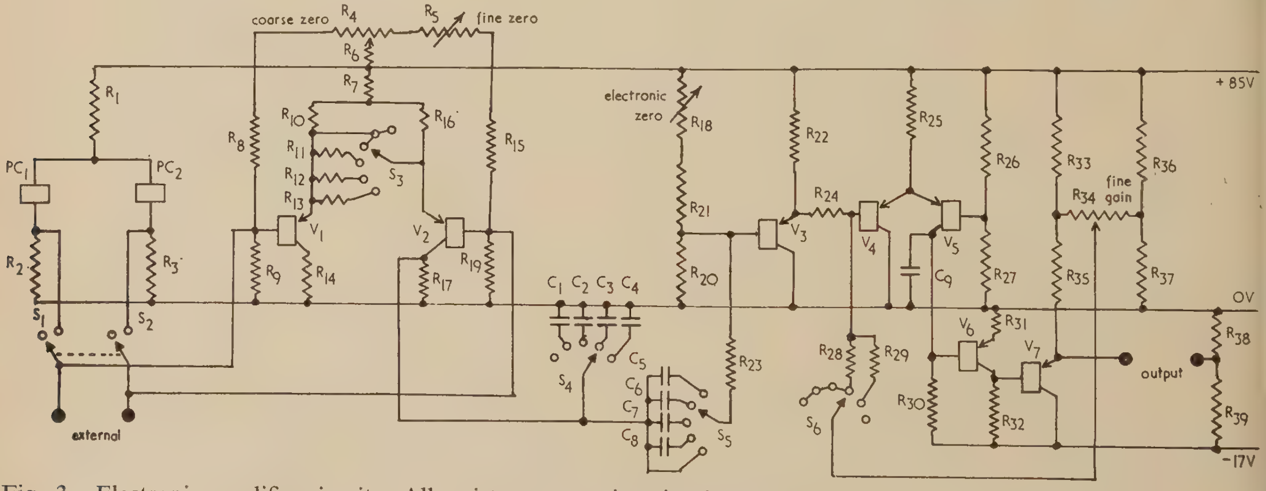

Fig. 3. Electronic amplifier circuit. All resistances are given in ohms, and capacitances in farads. Switches S_3 and S_6 are ganged. All potentiometers and all resistors associated with the input circuit are wire-wound. All other resistors are high-stability carbon of ±10% tolerance. It may be necessary to alter the value of R_{20} to suit individual transistors. All capacitors are paper or low leakage current electrolytic

R_1 = 30 kΩ
R_2 = 10 kΩ
R_3 = 10 kΩ
R_4 = 10 kΩ Variable
R_5 = 500 Ω Variable
R_6 = 30 kΩ
R_7 = 100 kΩ
R_8 = 100 kΩ
R_9 = 10 kΩ
R_{10} = 10 kΩ
R_{11} = 680 Ω
R_{12} = 2·2 kΩ
R_{13} = 6·8 kΩ
R_{14} = 10 kΩ
R_{15} = 100 kΩ
R_{16} = 10 kΩ
R_{17} = 10 kΩ
R_{18} = 100 kΩ
R_{19} = 10 kΩ
R_{20} = 39 kΩ
R_{21} = 1 MΩ
R_{22} = 100 kΩ
R_{23} = 10 kΩ
R_{24} = 22 kΩ
R_{25} = 47 kΩ
R_{26} = 220 kΩ
R_{27} = 10 kΩ
R_{28} = 330 kΩ
R_{29} = 1 MΩ
R_{30} = 10 kΩ
R_{31} = 47 Ω
R_{32} = 10 kΩ
R_{33} = 100 kΩ
R_{34} = 50 kΩ
R_{35} = 6·8 kΩ
R_{36} = 150 kΩ
R_{37} = 10 kΩ
R_{38} = 100 Ω
R_{39} = 1·5 Ω

C_1 = 6 μF
C_2 = 12 μF
C_3 = 25 μF
C_4 = 50 μF
C_5 = 1 μF
C_6 = 2 μF
C_7 = 4 μF
C_8 = 8 μF
C_9 = 0·1 μF

$\left.\begin{matrix} PC_1 \\ PC_2 \end{matrix}\right\}$ = FT435

V_1–V_7 = OC71

ock, and the two transistors are selected to have approxi-ately equal (within ±20% say) values of I_{CO}', I_{CO}' and α'. ie ganged switches S_1 and S_2 are used to disconnect the nplifier from the bridge so that its performance may be dependently checked. If for any reason the output for e photocell bridge contains unwanted high frequency gnals of large amplitude, a capacitor may be connected ross the "external" terminals. In most applications, wever, the integrating network R_{17} and C_1, C_2, C_3, or C_4 used to limit the high frequency response.

In certain applications, one of which is mentioned below, is desirable to differentiate the signal generated by the tical lever; suitable capacitors C_5 to C_8 may be brought to the circuit by the switch S_5, and the amplifier zero is en set by means of R_{18}. Should this facility not be quired, the emitter follower stage V_3 may be omitted, nce V_3 is included merely for the sake of its high input npedance which reduces the values of C_5 to C_8 required to ve a differentiating network of adequate time constant.

The linear output of the amplifier is sufficient to drive mmonly used pen recorders (4 mA in 3 kΩ, or 10 mA in kΩ), but to prevent damage to the recorder, the output age is designed so that the output voltage cannot exceed e limits −1 and +14 V (approximately). It should be oted that this limitation in output can give rise to non-nearity in response to large signals when the differentiating rcuit is in use unless the response time of the recorder is ppreciably less than the time constant of the differentiating rcuit. The effect is small and is normally negligible in the oisy conditions under which the differentiating network is kely to be used. The ganged switches S_3 and S_6 give a oarse control of gain and R_{34} a fine control. The maximum ain available (i.e. no feedback applied) will depend some-hat on the particular transistors employed—in the proto-pe full output is obtained for an input voltage of about 0 μV or an input current of about 0·1 μA. In general, aximum gain is used only for checking the electronic stem. At minimum gain full output corresponds to an put signal of about 100 mV.

The noise and zero drift arising in the electronic amplifier self depend somewhat on ambient conditions, but are ormally at least an order of magnitude less than the noise nd zero drift arising in the optical lever and photocells.

It is convenient to include in the amplifier case a meter hich may be switched to observe the output voltage, the put voltage and the output from the first stage; this has een omitted from the diagram in the interests of clarity. is necessary to monitor the output of the first stage when e differentiating network is in use to ensure that slow drifts the optical lever system do not cause the first stage to aturate.

The power supplies for the amplifier are obtained by half ave rectification from a standard mains transformer having 250–0–250 V secondary winding. The +85 V line is abilized by means of a neon tube (type 85 A2 by Mullard td.) and the −17 V line by means of Zener reference diodes ypes Z2A100 and Z2A68 by Standard Telephones and ables Ltd.) in series. The power supplies for the lamp are btained from the same transformer by connecting its two lament windings (6·3 V and 5 V) in series; a full wave ridge rectifier is used, and the stabilizing system is essentially milar to that discussed by Brown and Stephenson.(6)

PERFORMANCE

The best useful sensitivity obtained with a fixed mirror of mm² area is indicated by Fig. 4, which shows a record of the amplifier output. The recording bandwidth is about 0·1 s, and the r.m.s. of the zero variations corresponds to rather less than 10^{-10} rad movement of the optical lever mirror. Records as free from drift as that of Fig. 4 are not easy to attain, since the movement of any source of heat in the room is liable to produce some detectable change in the relative positions of the components of the optical lever. This record indicates, however, the extent to which internal sources of noise in the lever and amplifier have been reduced. The precautions necessary to secure this result are generally similar to those described in detail in a previous paper.(3)

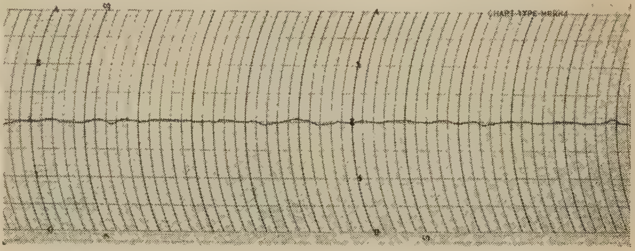

Fig. 4. Record showing stability with fixed mirror

1 vertical division ~$1 \cdot 5 \times 10^{-10}$ rad.
1 horizontal division = 2 s.

It is worth noting that the conventionally defined resolving power of the optical lever mirror is about 3×10^{-4}; the lever thus detects a change in position of the centre of the diffraction pattern from the mirror no greater than one millionth of the half-width of the pattern. This fact underlines the distinction between resolving power and accuracy of measurement.

The resolving power of the mirror cannot, however, be made indefinitely small in the present system, since it has to produce a well resolved image of the grid G_1. It is this consideration that needs a resolving power of the order of 10^{-3} to 10^{-4} rad, which in turn requires a mirror of about 1 mm in width. The area of the mirror must at least be such as to give enough photons on the photocells to make the statistical fluctuations in their numbers result in less "noise" than that in the system to which the mirror is attached as an indicating device. Since we are interested in an angular sensitivity of the order of 10^{-6} of the half width of the diffraction pattern, we need at least 10^{12} photons falling on the photocells within the observation time, or a flux of a few times 10^{12} photons/s. This estimate is likely to be a minimum figure, since it ignores both the current noise and the statistics of the photoelectric process in the photocells. The small amount of available data(1) on the minimum detectable energy for Schwarz cells (about 10^{-12} W for 1 c/s bandwidth) suggests that current noise may be comparable with, but not seriously in excess of, the photon noise in the present application. A mirror area of 2 mm² has been found to give some hundreds of lux on the photocells, which corresponds to a flux of the order of a few times 10^{12} photons/s, and it therefore appears that the mirror could not be made substantially smaller without appreciable "noise" being generated in the system owing to uncertainties in photon counting. Indeed, an increase in noise has been observed with smaller mirrors.

The primary concern of the present investigation has been the achievement of maximum sensitivity; linearity, freedom from fatigue, and long term stability have not been closely examined, but they have not been found deficient in any of the applications described below. They are probably of the same order as those given for earlier systems(3) with deviations from linearity of the order of 1% (without feedback) and long-term stability of the order of 10^{-7} rad/h.

On the scale of the original record of Fig. 4, incidentally, one micron of movement of one edge of the mirror would correspond to a deflexion of 10 km. Using a suitable lever technique(7) one micron displacement can be magnified up to 200 km if desirable.

APPLICATIONS

The system can be used to measure any physical quantity that can be made to cause a change of direction of a light beam. For example, Fig. 5 shows a record of the expansion of a lithium fluoride crystal under irradiation by X-ray The specimen size was 10 × 10 × 0·5 mm, and it w mounted alongside a similar specimen which was screened fro the X-rays. A mirror was fixed across the end faces of th two specimens, so that any relative change in length betwe the two would cause the mirror to rotate. Fig. 5 shows th the irradiated crystal begins to expand under X-ray bombar ment (intensity estimated at about 3×10^{-4} W/cm²) from molybdenum target, and to contract again when the X-ra are switched off. The expansion and contraction might due to *F*-centre creation and decay, but they might also be simple thermal effect; further investigation is being mad Full scale deflexion on the record corresponds to an expansio of about 10^{-8} cm. The small change of zero in the reco before the X-rays are switched on is due in some way to th movement of the operator in the room; the nature of th effect has not yet been ascertained.

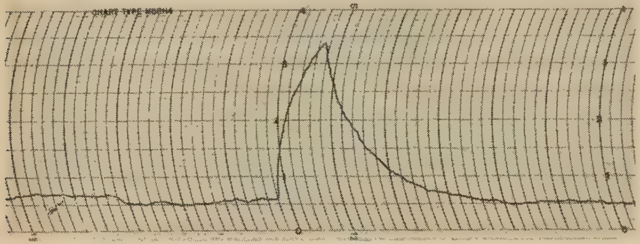

Fig. 5. Record showing expansion and contraction of a 1 cm long lithium fluoride crystal with onset and cessation of X-ray bombardment

1 vertical division ~2×10^{-10} cm.
1 horizontal division = 2 s.

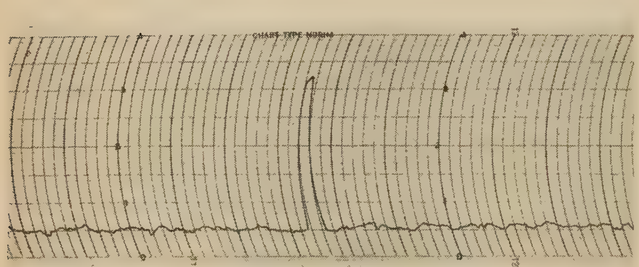

Fig. 6. Record showing response of system when used as a refractometer. The calibrating pulse is made by a temporary refractive index change of about 10^{-7}

1 horizontal division = 2 s.

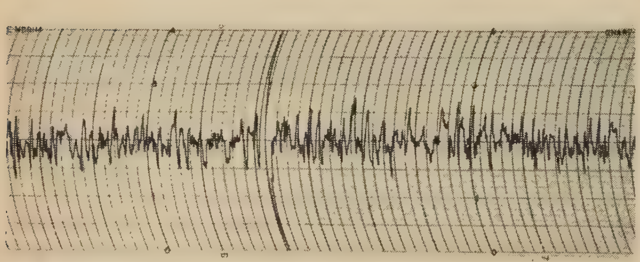

Fig. 7. Record showing output when signal from a linear expansion infra-red detector is differentiated. Calibration signal ~4×10^{-10} W. "Noise" on record represents velocity of the end of a 5 mm long, 0·1μ thick, constantan strip at 290° K in radiative equilibrium with surroundings

1 vertical division ~30μ/annum.
1 horizontal division = 2 s.

A sensitive refractometer for gases has also been mad using the same general layout, with a 60° hollow glass pris inserted between G_1 and L_2 and with the mirror *M* fixe If the refractive index of the gas within the prism differs fro that of the surrounding air, the direction of the light traversin it is slightly changed, and this shifts the image of G_1 relati to G_2. Fig. 6 shows a record of the amplifier output whe the pressure of the air is changed by about 0·2 mm mercur pressure, giving a refractive index change of about 10^{-} From the record it appears that a change of 3×10^{-9} shoul be detectable, and this might be improved since no stringen precautions were taken in making the record.

The application for which the optical lever has been mos used is that of an experimental infra-red detector dependin on the linear expansion of a thin metal strip.(7) In th application, the techniques of converting expansion int rotation, and of the subsequent measurement, have bee sufficient to detect displacements of less than 10^{-12} c The difficulty of maintaining a stable zero at this sensitivit has been obviated by differentiating the output of the bridge Fig. 7 shows a record made when a 5 mm blackened strip o constantan *in vacuo* was subjected to the switching on and o of a thermal signal of about 4×10^{-10} W from a black bod at 200° C. The total expansion was about 4×10^{-10} cm and since the record is a differential one it shows the velocit of the end of the strip during expansion and contraction The sensitivity is such that one division corresponds to velocity of the order of 30 microns/century; about one hal the "noise" on the record is due to the spontaneous change in length of the strip as its temperature fluctuates through thermal photon exchange with its surroundings.

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Evaporation of metals by electron bombardment

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[*Paper first received* 12 *August, and in final form* 23 *October*, 1958]

The rate of deposition of films of several metals, evaporated by maintaining a pendant molten drop by electron bombardment, is found in most cases to agree with that expected on kinetic theory. The analysis enables the usefulness of the method for other metals to be judged.

e method of evaporating metals from a pendant drop ich is maintained molten by electron bombardment has en recently applied by Kelly$^{(1)}$ to the evaporation of ntalum and zirconium. The method possesses the great vantage over that of employing a boat or filament in that re is no possibility of contamination of the film by the at material. The feasibility of the method would appear depend on two properties of the metal, namely, the surface sion and the vapour pressure at the melting point. If the face tension is too low, it proves difficult to hold a drop bly. If the vapour pressure at the melting point is too v then the rate of evaporation may be too low to be useful. om the nature of the process, the temperature of the drop s very close to the melting point of the metal.

Table 1. *Measured rates of deposition and the values of C′*

Metal	*M*	*p (mm Hg)*	*r (mm)*	*T (°K)*	*m (g cm⁻² s⁻¹)*	*C′*
Fe	56	$1{\cdot}8 \times 10^{-2}$	3·0	1808	$3{\cdot}1 \times 10^{-7}$	$1{\cdot}1 \times 10^{-5}$
Ni	59	$5{\cdot}6 \times 10^{-3}$	2·8	1728	$1{\cdot}5 \times 10^{-7}$	$1{\cdot}8 \times 10^{-5}$
Mo	96	$3{\cdot}5 \times 10^{-2}$	0·60	2893	$2{\cdot}6 \times 10^{-8}$	$1{\cdot}1 \times 10^{-5}$
Ag	108	$2{\cdot}5 \times 10^{-3}$	2·2	1233	$5{\cdot}6 \times 10^{-8}$	$1{\cdot}6 \times 10^{-5}$
Ta	182	$1{\cdot}8 \times 10^{-3}$	2·0	3120	$5{\cdot}8 \times 10^{-8}$	$3{\cdot}3 \times 10^{-5}$
W	184	$1{\cdot}5 \times 10^{-3}$	1·0	3640	$1{\cdot}9 \times 10^{-7}$	$5{\cdot}6 \times 10^{-4}$
Pt	195	$1{\cdot}7 \times 10^{-4}$	1·4	2049	$1{\cdot}6 \times 10^{-9}$	$1{\cdot}6 \times 10^{-5}$

The rate of evaporation per unit area of surface of a bstance of molecular weight M at absolute temperature T given by:

$$G = p(M/2\pi RT)^{\frac{1}{2}} \qquad (1)$$

ere p is the vapour pressure and R the gas constant. If aporation takes place from a sphere of radius r, the mass material arriving per second on a surface at distance d is ven by:

$$m_a = Cr^2G/d^2 \qquad (2)$$

ere C is a constant and the assumption $r \ll d$ is made. these experiments $d = 5{\cdot}5$ cm.) If all the incident atoms ndense and if the source-target distance is kept constant, may write for the mass m of evaporant condensing per it time

$$m = C'r^2p(M/T)^{\frac{1}{2}} \qquad (3)$$

r the case considered, T is the melting point and p the pour pressure at this temperature. The assumption of ity for the accommodation coefficient is known to be stified for many metals. Notable exceptions are zinc and dmium. Equation (3) shows that the expression $T^{\frac{1}{2}}/r^2pM^{\frac{1}{2}}$) should be constant. It is of interest to see to at extent this result holds for a number of metals.

Measurements of the thickness of films of iron, nickel, ver, tantalum, tungsten and platinum were made using zeau fringes. The value of m was then calculated on the sumption that the density of the film was equal to that of e bulk metal. In the case of iron, the mass of film was determined microchemically and the assumption confirmed to within approximately 2–3% for this metal. From the values of m, r, M and from the vapour pressures p (sometimes extrapolated over a rather wide temperature range) the value of C' was determined. The results are given in Table 1.

The agreement in the values of C' is reasonable in the light of the uncertainties in vapour pressures and film densities. Tungsten gives an abnormally high value, indicating a higher rate of transfer than would be expected. This may be due to the reaction of tungsten with residual water vapour in the system.$^{(2, 3)}$ The pressure in the system, as indicated by a Penning gauge, was approximately 1–2×10^{-5} mm of mercury.

Taking a mean value for C' as approximately $1{\cdot}8 \times 10^{-5}$ we may calculate the rate of deposition of films of other metals if their vapour pressures at the melting point are known. The usefulness of the method may thus be judged for such metals. Table 2 gives the values of m calculated for an evaporating drop of radius 2 mm for the metals titanium, copper, zirconium and gold. In the last column the rate of deposition in Angström units per second is given, assuming that the films have the bulk density.

Table 2. *Predicted rates of deposition for Ti, Cu, Zr and Au*

Metal	*m (g cm⁻² s⁻¹)*	*Rate of deposition (Å/s)*
Ti	$1{\cdot}3 \times 10^{-7}$	2·9
Cu	$4{\cdot}4 \times 10^{-9}$	0·049
Zr	$8{\cdot}7 \times 10^{-10}$	0·014
Au	$1{\cdot}8 \times 10^{-10}$	0·001

The method should therefore be highly satisfactory for titanium: it has been used successfully for zirconium. With gold the rate of deposition has been observed to be extremely low.

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Laboratory and workshop notes

Multi-channel time recorder for time and motion studies

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(*Note first received* 9 *April, and in final form* 18 *June*, 1958)

In recent years a considerable amount of interest has been taken in the application of time and motion studies to the management of the cow-shed. A few preliminary studies have been made at this Station using conventional methods, but unfortunately, because of the difficulty in training workers in the use of the ordinary techniques which involve the use of stop-watches and notebooks, it has not been possible to pursue these studies to any great extent. The conventional method is to watch the movements of the farmer and the responses of the cows, making a note of the elapsed time on a stop-watch. This is not easy and a considerable amount of experience is needed before reliable results can be obtained.

A physiological time recorder was regarded as a possibility for recording the events occurring at milking time, but two difficulties arose. First, there was the problem of identifying the marks on the line drawn by the timing pen, and second there was the problem of maintaining with complete reliability a continuous ink line. The ordinary recording pen was not found reliable enough. The former problem, however, was more serious than the latter. It is important in the timing of the processes involved in milking to be able to identify the intervals unambiguously. After some preliminary work it was decided to use automatic telephone dials as the switches for controlling the time recorder. These telephone dials differ from the standard English makes in that they are numbered in the reverse order, i.e. 9–0, and the number of pulses does not, therefore, correspond to the number on the dial. In an orthodox telephone dial there is a pair of contacts which closes when the dial is rotated a short distance. The return of the dial to its normal position is controlled by a small centrifugal governor and during the return motion a second set of contacts supplies pulses which are characteristic of the number dialled. By connecting the two sets of contacts in series it was possible to use the telephone dial so that the timing pulse was applied to the recorder the moment the dial was rotated through a small angle. This is followed by the characterizing pulses and it is thus possible using a standard telephone dial to obtain ten different markings with a single movement.

An experimental time recorder, based on the physiological timer made by C. F. Palmer (London) Ltd., was made up using Teledeltos electrosensitive paper (by Standard Telephones and Cables Ltd.). This type of timer has three writing arms which are moved sideways by 6 V electromagnets. The tips of the arms were insulated and connected to a source of alternating voltage, through a resistance, to supply the current needed to mark the paper. The movements of the arms were controlled by the telephone dials energized by a 6 V dry battery. The mechanical drive of the recorder was modified to give the speeds set out in Table 1.

It was found that if the Teledeltos paper was used in a draught there was a tendency for the trace to widen owing to burning. Pressure sensitive wax-coated recording paper was then tried. Using sapphire-tipped gramophone needl (0·003 in. radius tip) a very satisfactory recording w obtained and this method was finally adopted, so eliminati the need for an electrical voltage to energize the writing par

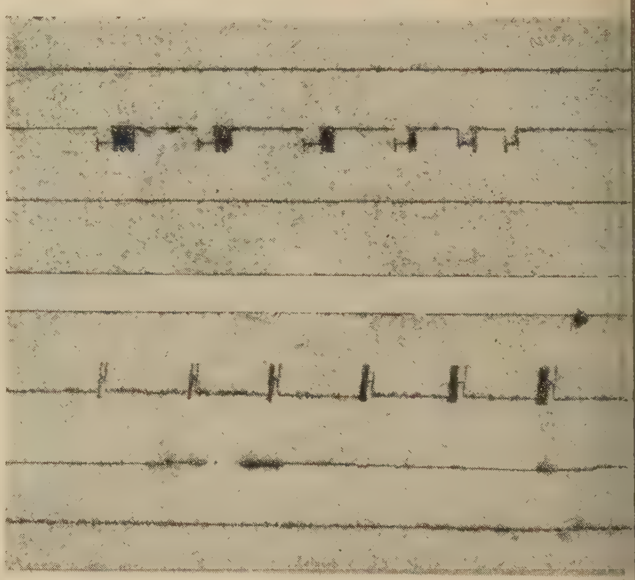
The setting of the speed of a recorder of this type is n easy because the governor, being of a centrifugal type, h no absolute basis as would be the case if a synchronous mot were used. To overcome this difficulty a photographical reduced version of a gramophone stroboscope was fitted the vertical drive spindle of the Palmer recorder. The wor reduction gearing was 1 : 60 and this gave the speeds list in Table 1.

Table 1. *Range of recorder speeds*

Drive spindle speed (rev/min)	*Paper speed (cm/min)*
$33\frac{1}{3}$	4.73
45	6.39
78	11.07

The lower speed range of 4·73 cm/min is quite adequa for time and motion studies connected with milking and th speed can be set quickly provided that an electric lam running from a 50 c/s source is available.

The record consists of an initiating pulse followed by series of pulses which indicate the number dialled (see th figure). For most purposes it is not necessary to use th ten numbers on the dial and it simplifies the recognitic of the different marks if the even numbers only are use This is particularly true at the lower speed of 4·73 cm/mi when the marks tend to run together. One limitation



Illustrating the type of trace left on the recording paper. The upper figure from left to right shows the markings corresponding to the dial numbers 0, 2, 4, 6, 8, and 9 for a paper speed of 11·07 cm/min. The lower diagram shows the marks corresponding to 9, 8, 6, 4, 2, and 0 read from left to right for a paper speed of 4·73 cm/min. The telephone dials used are numbered in reverse so that 9 corresponds to 1 "blip" and 0 to 10. The difference in dial number can be detected quite readily in the nature of the trace s method is imposed by the time taken for the dial to urn to zero. This interval is of the order of one to one d a half seconds and it is impossible to record two events curring within an interval of about two seconds if one of e lower dial numbers is used. Fortunately for records in e cow-shed this is of no significance.

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It was thought that some error might occur in initiating the ning pulse as a result of the difference in the dialling operaon between zero and nine, the two extremes of the dial. ble 2 sets out the intervals recorded for paper running at 73 cm/min when thirty second intervals as read from a stoptch were dialled using nines and zeros. As can be seen ere is no serious error involved due to differences in the alling movement. It would appear that over an interval the order of five minutes the accuracy of recording with paper speed of 4·73 cm/min is of the order of 0·4%, which much higher than necessary for the type of study for which e recorder was designed.

Table 2. *Test results on telephone dial timer (30 s interval)*

								means
tervals between 9's	2·36	2·35	2·39	2·35	2·36			*2·36*
tervals between 0's	2·40	2·34	2·41	2·36	2·38			*2·38*
tervals between 9 and 0	2·34	2·37	2·39	2·38	2·34	2·29	2·39	*2·36*

It will be apparent that this system can be used in any ıdy where a variety of observations is needed simulneously, and if more than ten events were being recorded, ovided that the dial return times did not introduce too much ad time, there is no reason why double marks should not used, or in the case of longer intervals triple marks, thus aking it possible to record 99 and 999 events.

Controlled-atmosphere electric furnace

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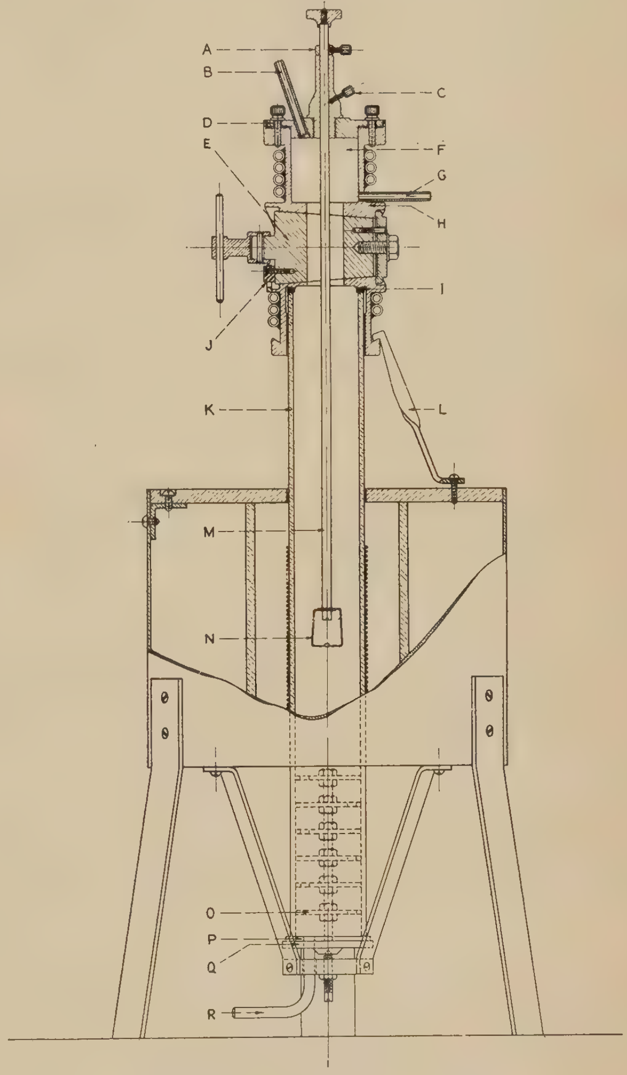
[*Note received* 25 *April*, 1958]

he electric furnace to be described allows a sample to be troduced and removed from the hot-zone while an inert mosphere is maintained.

The furnace (see figure) consists of a recrystallized alumina ıbe *K*, 18 in. long by $1\frac{3}{4}$ in. internal diameter. Platinum/20% ıodium wire, 0·020 in. diameter, is wound around the ntral part of the tube over a length of about $4\frac{1}{2}$ in. with a acing of 8 turns/in. The vertical tube is enclosed in a rnace casing 8 in. high insulated with alumina and agnesia-asbestos.* The tube projects 5 in. beyond each ıd of the casing so that its ends are kept as cool as possible. he bottom of the tube is supported on a self-alining bracket , suspended from the bottom of the furnace casing, and is aled with a neoprene gasket *P*. An inlet *R*, for inert gas, provided in this bracket. The top of the tube is closed by specially designed brass cap *H*, containing in its central art a large brass gas-type "tap" *E*, with 1 in. bore, which parates the main furnace tube from a small chamber *F* bove the "tap," this chamber is closed at the top with a lid *D* which can be clamped down tightly by thumb screws passing through slotted holes designed for quick release. The chamber has a gas inlet *G* and outlet *B*, and through its lid projects a nickel rod *M*, $\frac{1}{4}$ in. diameter, carrying on its lower end a small nickel stirrup *N* to hold the sample, and so arranged that when the "tap" is turned to the "on" position the rod carrying the sample can be passed down into the hot-zone of the furnace. An adjustable stop *A* on the rod ensures repeatable positioning of the sample in the hot zone; the rod is secured in its upper position by a clamp *C* in the boss on the lid of the chamber. The brass cap is held down on top of the alumina tube by clamps *L* attached to the top of the furnace casing and a neoprene seal *I* is provided between the tube and cap for gas tightness. To allow for the thermal expansion of the tube the clamps are tightened only when the furnace is hot.



Controlled-atmosphere electric furnace

In operating the furnace the rod is removed from the lid, the "tap" turned "on," and a thermocouple passed down through the lid as a temperature check. When the furnace is at the desired temperature the thermocouple is removed and the rod replaced, in its upper position, in the lid. The furnace is flushed out with inert gas (e.g. oxygen-free nitrogen) for one hour before use. The "tap" is now turned "off," thus isolating the chamber from the main furnace body. The lid is then removed and the sample placed on the stirrup. Finally the lid is replaced and tightened down. Next the air in the top chamber is swept out by passing a current of inert gas for 10 min. Afterwards the "tap" is turned "on" and the sample lowered by means of the rod into the hot-zone of the furnace and heated for a predetermined period. At the end of this period the rod is raised to bring the sample into the top chamber and the "tap" is closed. The sample is allowed to cool in a current of inert gas and then retrieved by unclamping the lid. During the whole operation a positive gas pressure, as indicated by a water manometer, is maintained in the furnace.

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* Segnit, E. R., and Wolfe, J. D. *Chem. Eng. Min. Rev. ustr.)*, 45, p. 215 (1953).

The "tap" is lubricated with molybdenum disulphide powder and is fitted with two stops *J* to permit accurate opening and closing and to prevent the stirrup from being fouled on the partly opened "tap." Water cooling coils are provided when the furnace is operated above 900° C, partly to maintain easy movement in the tap, but mainly to protect the neoprene seal, but the furnace has been operated safely to 1100° C. The neoprene seal at the bottom of the tube is protected from direct radiation by a series of asbestos disks *O* perforated to permit passage of gas, and supported on a rod. During operation the furnace temperature is controlled by an a.c. bridge circuit.

Bellows-operated water switch

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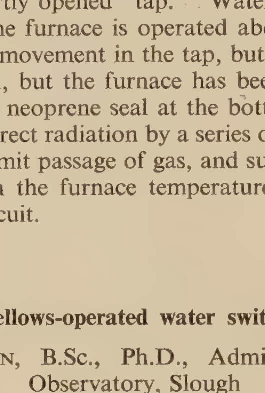
[*Note received* 18 *June*, 1958]

A water switch, which has proved suitable for inclusion in a diffusion pump cooling circuit, is described below. A T-piece *A* of metal tubing is firmly fixed to a base plate *B* and included in the rubber tubing *C* of the water supply as shown in the figure. To the third limb of the T-piece is soldered a length of metal bellows *D* closed at the free end. This end bears on the operating key of a microswitch *E* which is attached to the base plate by a single screw *F*. Adjustment of the screw *G* allows of easy positioning of the microswitch relative to the bellows. The triangular shape of the base plate is chosen to enable the rubber tubing attachments to be made and secured after assembly of the unit. The T-piece can be held in direct contact with the base plate without recourse to packing, if a hole is cut in the latter to allow free moveme of the bellows. A small tube clamp *H* is fitted on the out side of the switch. By means of the fixing screws *I* the u may be mounted on a control panel, bench, or in some oth convenient position.



A bellows-operated water switch

The manufacturers of metal bellows recommend that th should not be used in extension. Thus a small compressi spring may be fitted between the bellows and microswitch ensure that operation does not involve extension beyond t free length. Such a procedure has, however, been fou unnecessary in the present application where trouble-fr service has been obtained for a number of years from bellow suffering extensions of up to 10% of free length.

The sensitivity of this type of water switch is determin by a number of factors including bellows stiffness, micr switch operating force and the impedance of the water outl line. The required sensitivity is obtained by adjustment the screw *G* and clamp *H*. This latter item may be necessa only for small flow rates, in order to increase the impedan of the outlet. By such adjustments the switch can be ma to operate successfully at any flow rate between $\frac{1}{4}$ and 2 l/m for $\frac{1}{4}$ in. inner diameter tubing. The switch re-makes conta at a flow approximately 0·1 l./min greater than the "break value.

The device described is simple to make, yet robust a dependable in service, with easily variable sensitivity. B suitable choice of microswitch the main electrical supp may be broken directly without recourse to relay system and since there is no fear of water spillage, proximity of t unit to electrical equipment or distance from a drain is of n consequence.

Zone refiner for laboratory use

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[*Note received* 23 *June*, 1958]

We have constructed a device for the laboratory zone refinin of silver bromide, the operation of which we believe to b novel, and which could probably be adapted to other zon melting applications. It combines the advantage of th continuous operation obtainable with a circular charge i a single batch technique, with the possibility of enclosing th charge in a straight tube. The silver bromide ingot is seale in an evacuated glass tube. Several molten zones, produce by electrical resistance heaters, travel down the tube. As molten zone moves off the end of the tube, it immediatel reappears at the other end. This operation is achieved b providing a series of closely spaced, stationary heating coil along the entire length of the ingot. Current is supplied t the coils successively by means of a slowly turning rotar switch. Each heating coil is attached to one of the stationar switch contacts arranged on the circumference of a circle and the circuit is made by a rotating contact. The numbe of rotating contacts is equal to the number of zones which are simultaneously moving down the tube. This princip involves no waste of power or time, since every heated coi is melting the charge and the molten zones are always space as closely as possible all along the charge. The operatio can be made fully automatic.

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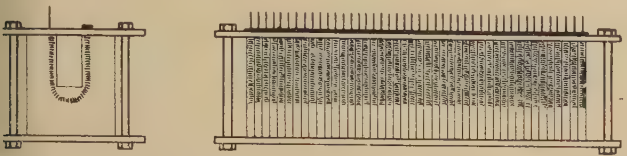
* Now at Massachusetts Institute of Technology, Cambridge, Mass.

The device we have constructed is suitable for a low-melting ibstance such as silver bromide (melting point 422° C) hich can be contained in a tube. It comprises 44 U-shaped eating coils, $\frac{3}{4} \times 1\frac{1}{4}$ in., spaced at about $\frac{1}{8}$ in. intervals, as iown in the figure. The coils are made of 0·020 in. diameter iromel wire, closely wound on $\frac{1}{16}$ in. drill rod as a form, id each coil has a resistance of 4·5 ± 0·2 Ω. The coils re separated by mica spacers.

One end of each heating coil is attached to a common us-bar, and the other end is attached separately, in sequence, one of the 44 stationary contacts of the rotary switch, hich was salvaged from an old rheostat. The bus-bar and ie rotating contacts of the switch are connected across a ource of a.c. power. There are two rotating contacts at pposite ends of a diameter, so that two equally spaced zones ogress along the ingot. The contacts are wide enough so at each coil is turned on about 15 s before the preceding il is turned off. The stationary contacts corresponding to e first three coils are all connected together, so that the st three coils are heated together for three times as long as e other coils, in order to initiate melting at the cold end the charge.



Heating coils for zone refiner

The rotary switch is turned by a variable speed motor hich is geared down to give rates between about 0·5 and 0 rev/h. Since the charge is about 6 in. long, there are o zones spaced 3 in. apart travelling at rates which can be ljusted between 3 and 12 in./h. With the silver bromide rtially filling an evacuated 12 mm Pyrex tube, a voltage of V across the coils gives a molten zone about $\frac{1}{4}$ in. long at e highest rate of travel. The number of passes is counted a mechanical counter which is actuated by the rotating ntacts of the switch. An electric timing clock turns the vice off after any time up to 12 h.

We are grateful to J. D. Foch and E. Fukushima for sistance in the construction of the device.

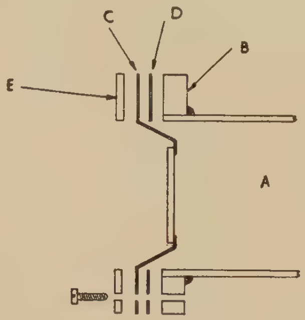
Coolable vacuum-tight window seals for optical use

By V. Roberts, B.Sc., F.Inst.P., Royal Radar Establishment, Malvern, Worcs.

[*Note received* 10 *September*, 1958]

versatile method for sealing various optical materials to e low temperature parts of metal cryostats has already been scribed,(1) and has been in regular use in this laboratory wn to liquid helium temperature, during the past four ars.(2, 3)

Briefly, the window in the form of a 1 in. diameter disk is aled with Araldite (by Aero Research Ltd.) to a suitable pper diaphragm which is then soldered to the cryostat th Wood's metal. Although this scheme works quite satisctorily the life of the window assemblies would be prolonged, and time saved in window changing if the diaphragms could be sealed to the cryostat without soldering or otherwise applying heat to them. Furthermore, gradual corrosion of the absorption cell by soldering fluxes would be eliminated. It seemed likely that a suitably shaped diaphragm could be satisfactorily sealed by a polythene gasket,(4) and the following design was evolved and fitted to a previously described absorption cell(2) after preliminary tests at 77° K. It should be noted that when space is very limited, as in a cryostat for magneto-optical measurements(3) for example, the original soldering method usually allows a more compact assembly to be made.



Window seal assembly

In the figure, *A* represents the specimen chamber to which a flange *B* is permanently soldered. An annular polythene gasket *D* 0·005 in. thick and about 0·40 in. wide is clamped between *B* and the window diaphragm *C* by the retaining ring *E*. The assembly is held together by sixteen 10 B.A. screws, *B* being tapped to receive them and *E*, *C* and *D* appropriately perforated. It is advisable to smear the gasket lightly with vacuum grease before assembly. A polythene window 0·005 in. thick may be clamped between *B* and *E* if desired or a smaller polythene window can be used by first sealing a reducing flange of the required size to *B* with a polythene gasket.

Seals of this type have been in frequent use at liquid hydrogen and helium temperatures for several months and have proved thoroughly satisfactory. Window and specimen changes can be effected very rapidly and the seals show little sign of deterioration with use. By suitable choice of window materials the whole spectral range from the ultra-violet to the far infra-red can be very adequately covered.

The suggestion that polythene gaskets might be used in this way was made by Mr. P. Smithers, and the detailed design and testing of the seals was carried out by Mr. R. C. B. Channon. This note is published by permission of the Controller, H.M. Stationery Office.

REFERENCES

(1) Roberts, V. *J. Sci. Instrum.*, **31**, p. 251 (1954).

(2) Roberts, V. *J. Sci. Instrum.*, **32**, p. 294 (1955).

(3) Roberts, V. *Colloquium Spectroscopicum Internationale VI* (*Amsterdam*, 1956), p. 508 (London: Pergamon Press Ltd., 1958).

(4) Warschauer, D. M., and Paul, W. *Rev. Sci. Instrum.*, **27**, p. 419 (1956).

Correspondence

Simple attachment to the Sucksmith ring balance for use at low temperatures

An apparatus is described which permits specimen temperatures steady to within 0·5° K over a continuous range between 20 and 300° K to be obtained in the Sucksmith ring balance. In the design, the primary requirement was that the apparatus should be capable of use within a small space. A magnet pole gap of no greater than about 17 mm was available, and to allow satisfactory measurement of magnetization using the Sucksmith ring balance an internal free diameter of no less than 8 mm was desirable. Also, the system had to be economical in its consumption of cooling liquid.

The general layout of the system is shown in Fig. 1. There are two co-axial tubes, both closed at their lower ends. The outer one is made entirely of thin-walled German silver, and in operation all its lower part is immersed in a bath of the cooling liquid contained in a shaped Dewar vessel. The inner tube is of thin-walled German silver from the top down to the point *Y*, where it is joined to a bottom part made of copper. Set inside this copper bottom is a small heater. Thermal contact between inner and outer tubes is made at the point *X* by means of a bridge (described below) made of copper. In normal use, the space between the two tubes is evacuated, so that the only significant heat transfer is *via* the bridge at *X*. Since the bridge is made of copper, both tubes are thus maintained at bath temperature at this position.

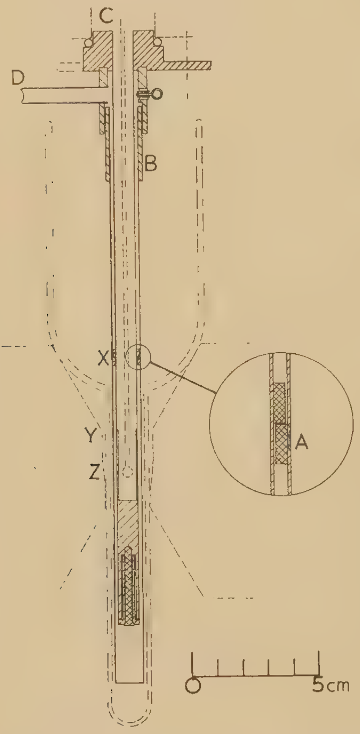


Fig. 1. Sectional drawing of the low-temperature device

The specimen under investigation is suspended from a thermally insulating support at the point *Z*, which lies inside the copper section. When the innermost space contains helium at low pressure as an exchange gas the specimen temperature is thus near that of the copper bottom. The temperature of the copper is controlled by balancing the heat input to the heater against the heat leak along th section of German silver tube *XY*. This kind of fixed hea leak was chosen in preference to any other with a view t providing better temperature stability.

The copper bottom of the inner tube was machined out o a solid rod, and soldered on to the end of the German silve tube at *Y*. The heater consists of about 120 turns of 42 s.w.g enamelled platinum wire of resistance about 20 Ω at roo temperature. Platinum was employed because it is easy t wind and was readily available in the required size, but othe materials would have been suitable. The wire is wound o to a bobbin of copper and protected above and below b layers of thin waxed paper. One end of the heater coil i soldered on to the upper end-face of the bobbin, so tha when the whole is assembled the body of the apparatus act as one lead. The other heater lead rests in a vertical channe in the copper (into which it is fastened by means of shellac and is taken up the outside of the inner tube to an insulate terminal at the top. This lead is made double over as lon a length as possible, to reduce its resistance. The part o the lead immediately behind the insulated terminal (t which it is soldered) is covered by fine glass fibre sleeving.

The arrangement of the copper bridge at *X* is shown enlarged in the insert to Fig. 1. It is made in two parts, on attached to each of the coaxial tubes. In order to fix th part *A* in position, the outer tube had to be broken, an afterwards rejoined. Appropriate slots were cut in thes parts to permit passage of the lead to the heater. Contac between the parts (which is essential in order that the inne tube be at bath temperature at *X*) is maintained by virtue o their being pushed together during final assembly.

The upper part of the system was designed to allow eas access to the heater. The German silver collar *B* is hard soldered to the outer tube. Final assembly consists of fittin the upper part of this collar into its recess and fastening i in place with soft solder. A short clearance space is left a its upper end to allow the bridge at *X* to be properly close by pressing the outer tube upwards during the solderin operation. The upper parts of the device, and also the par of the pumping line *D* attached to them, were made o German silver, which has a low thermal conductivity. Fig. shows the general arrangement of the vacuum system. It enables both the inner tube and the space between the tubes to be evacuated, either simultaneously or separately or made to contain the exchange gas. In practice exchange gas is usually admitted between the two tubes during initial pre-cooling of the apparatus and later pumped out. It is quite

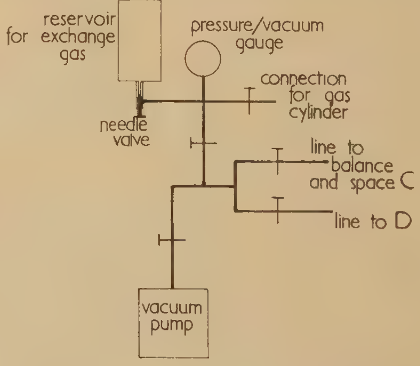

reservoir for exchange gas
pressure/vacuum gauge
connection for gas cylinder
needle valve
line to balance and space C
line to D
vacuum pump

Fig. 2. Schematic drawing of the vacuum system

sy to keep temperatures steady to within ±½° C indefinitely, manual adjustment of the heating current. The maximum nperature difference between cooling bath and specimen curs just below liquid nitrogen temperature (with the drogen bath) or just below room temperature (with the nitrogen bath). Under these conditions, the power input to the heater is about one watt. The consumption of liquid hydrogen in this state is about 10 cm^3/min, or of liquid nitrogen about 5 cm^3/min.

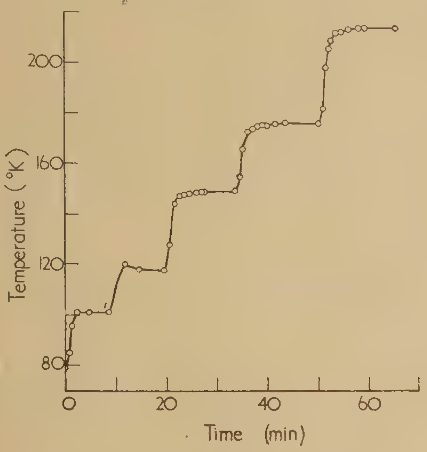


Fig. 3. Graph of specimen temperature against time using liquid nitrogen as the coolant

If during temperature changes upwards, relatively large heating currents (three or four times the steady current) are temporarily applied at the start of the change, steady states a few degrees apart can be obtained at intervals of less than ten minutes. Fig. 3 shows the kind of control that is obtained. During cooling the most rapid change is achieved by switching off the heater and temporarily admitting a little exchange gas into the space between the tubes. Here the temperature changes are rather more sluggish than during heating. Specimen temperatures are measured by means of a suitable thermocouple attached to and in good thermal contact with the specimen.

At the time of writing, two of these devices have been made. One has been in satisfactory operation for more than a year.

The authors are grateful to Mr. R. Rodgers for his skill in making the first device; and to Professor W. Sucksmith for his interest and advice.

Department of Physics,
The University,
Sheffield.

J. Crangle
M. J. C. Martin

[15 August, 1958]

NOTES AND NEWS

New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

ulation tester. Shaw Moisture Meters, 31 Market Street, Bradford, Yorks.

n insulation tester, manufactured by Messrs. K. P. undinger of Germany, is available to measure up to 10^6 MΩ n an approximately even logarithmic scale). The electrodes, rmanently attached to the instrument, are of a special nductive material and are designed for measurements on e surface of objects.

The meter is operated by a 22·5 V miniature battery, ich makes the instrument independent of mains connexions d ready for operation anywhere. Batteries are only under ad at the moment of contact, so they last for more than a ar.

This small, pocket-sized instrument is quick and easy to e and may be used for the detection of moisture on plaster ard or other surfaces.

rth lead tester. Gresham Transformers, Ltd., Hanworth, Middlesex.

is earth lead tester is the result of field tests lasting over a ar (in collaboration with H.M. Inspectors of Factories), portable electric tools and appliances. The instrument akes its rapid test by ascertaining the continuity and equacy of the earth lead of a tool or appliance, the supply ad of which is plugged into one of the standard three-pin ckets (5, 13 and 15 A) on the panel. The action is fourfold.

(i) The resistance of the lead before the main test is measured.
(ii) The main test. A heavy current of 100 A is passed through the lead for two seconds.
(iii) The resistance of the lead is again measured.
(iv) A mains voltage is applied to the tool or appliance to ensure that it, itself, is in working order.

It is stated that if the lead is defective to the extent of requiring examination, resistance (iii) will be higher than resistance (i). If there is an open-circuit the resistance (iii) will be infinite. If (i) and (iii) are identical, the lead is satisfactory.

Magnetic materials. Standard Telephones and Cables Ltd., Connaught House, Aldwych, London, W.C.2.

Standard magnetic materials have been used for more than forty years in the many fields of application where optimum magnetic characteristics have been required. These materials include molybdenum–Permalloy powder, Permendur and a range of Permalloy strip materials. The permeability of the powder materials ranges from 14 to 145 whilst the Permalloys cover from 2 000 to 50 000.

Another group of materials, under the registered name of Stanferite, has now been added to the range of magnetic materials with the object of bridging the permeability gap that exists. It is claimed that these materials have permeabilities ranging from 15 to 2 500.

They are of particular interest since they are non-metallic materials having high resistivity and consequently low eddy-current losses. This characteristic enables them to be used at much higher frequencies than was previously possible with metallic magnetic materials of similar permeability.

There are three main classes of the materials: (i) manganese zinc ferrite which has high permeability and low-loss at frequencies up to 1 Mc/s; (ii) mixed ferrite, having a rectangular hysteresis loop and therefore suitable for data-processing applications; and (iii) nickel zinc ferrite, having extremely low eddy-current and dielectric losses rendering it useful over a very wide frequency range up to 150 Mc/s.

They are available in many different shapes and sizes, suitable for magnetic cores of various instruments.

Valve voltmeter. Marconi Instruments Ltd., St. Albans, Hertfordshire.

The TF 1300 voltmeter has an a.c. measurement range from 0·1 to 100 V over the frequency range 20 c/s to 300 Mc/s. It also measures d.c. up to 300 V and resistances up to 5 MΩ. The indicating meter is direct-reading on a.c., d.c. and resistance ranges, and no correction factors are needed. Zero stability is stated to be of a high order with respect to both time and mains variation, and only one zero setting is required for all a.c. or d.c. ranges. Both a.c. and d.c. inputs are isolated from chassis. The circuit components are mounted on the rear of the sloping front panel, which hinges upwards for ease of servicing. Valve-base wiring and preset controls for calibration are concealed behind a quick-release meter surround. Operational presets are accessible in a case-top recess, which is also used for lead stowage. The recess lid hinges back to form a support which allows the instrument to be used, if required, in a 45° sloping position. A.C. measurements are made with a light-weight, cylindrical probe fitted with a polyvinyl chloride sheath and safety guard. The rectified output from the probe is applied to one arm of a valve bridge comprising two double triodes; a second arm of the bridge is coupled to a splash-current balancing network including a potential divider across the h.t. supply and a 3 V stabilizer element. For d.c. measurement, the input is applied directly to the bridge, and the probe unit and splash-current network are automatically disconnected. Fo resistance measurements, the unknown resistor is connecte in series with a standard resistor across the 3 V stabilize supply and the meter responds to the p.d. developed acros the unknown resistor.

Valve voltmeter

Precision tubes. Accles and Pollock Ltd., Oldbury, Birmingham.

Recent tube research and development has mainly been concerned with special metals and new tube fabrication processe to meet the increasingly specialized demands of moder science in industry. The following examples illustrate som of the results of recent developments and the scope o specialized tube work.

The manufacturers are experimenting with zirconium an its alloys, and beryllium which, it is claimed, have a lo capture of thermal neutrons, whilst at the same time wi slow the neutrons to thermal speeds. Tantalum, vanadium molybdenum, niobium and titanium all have special properti making them useful in constructing more efficiently su devices and apparatus as, for example, vacuum tubes, an the tubes necessary in nuclear engineering.

Helically convoluted tubing is being produced for tes purposes. This tubing is much more satisfactory than th fabricated type for both low and high duty application Various sizes have been produced, mainly in stainless stee and plain sections of specified lengths can be included i accordance with the apparatus design.

The demand for more efficient heat exchangers has led t the development of helically gilled tubing. Surface are ratios in excess of 3½ : 1 have been obtained in mild ste The ratio referred to is that between the outside surface of a gilled tube and a plain tube of diameter equal to that of th gill root. Development work is still proceeding, but it i hoped to produce tubes of up to 6 in. crest diameter (overal outside diameter) in lengths of up to 20 ft with surface are ratios in excess of 6 : 1.

Considerable development work has been carried out t improve techniques in the production of thin-walled tubin Cold drawn, seamless, thin-walled, stainless steel tubes i diameters up to 4¼ in., with thicknesses down to 0·010 in. have been successfully produced. In the smaller diameter of approximately ½ in., tubing has been made with a wal thickness of 0·004 in. Tubes below ½ in. can be made stil thinner. The minimum thickness depends upon severa factors such as tube diameter, length, material, etc.

Extremely fine bore thin-walled aluminium and aluminium alloy tubing is supplied in various shapes and sizes for the manufacture of those instrument pointers in which a low moment of inertia combined with strength is an important consideration. Tube sizes as small as 0·010 in. outer diameter with a wall thickness of 0·001 in. are included within this range. Small diameter stainless tubing is often used for pointers and recorder pen assemblies.

Pressure sensitive tubes, multibore tubes, including some of very small diameters, and non-ferrous tubes of unusual sizes are also available. Finally, for high-pressure applications it is claimed that some specially manufactured tubes with fine bores will stand pressures of 200 000 lb/in.^{2}

Magna gauge electronic comparator. Southern Instruments Industrial Division, Frimley Road, Camberley, Surrey.

It is claimed that this gauge, although only a comparatively new instrument, has already established itself as one of the

›st accurate and reliable instruments of its kind. By mbining the ability to read a total deflexion of ±0·005 in. th an accuracy extending down to 0·00001 in. all the plications of this type of instrument are covered in one it. The instrument is small, robust and portable; and, ing completely insensitive to normal mains and tempera- e variations, can be used with maintained accuracy in any uation. It is simple and easy to use, allowing operation by rsonnel without special skills and little gauging experience. gether with its accessories the gauge provides a flexible nge of equipment for semi- or fully automatic indication d control of dimension tolerances.

The sealed and practically indestructible gauge head can mounted on a comparator stand or machine in any desired sition. A simple flexible cable carries the electrical signal the remote indicating unit which can therefore be placed any convenient display position. The conversion of a ysical change to an electrical signal gives endless possi- ities as far as applications are concerned and the equip- ›nt only requires simple adaption to solve any particular oblem. The identical equipment can be used for manual automatic control.

A signal light indicator is also available to indicate tolerance iits by coloured light signals. This enables sizing or batch rting of workpieces to be carried out by unskilled operators. lay outputs are also available from this same unit for tomatic sorting or machine control. For example, in nding machine control the first relay contacts can be used change over to a lower rate of feed when the work is proaching size, and the second to stop the machine after e is reached. A number of other accessories are available special applications and others are under development iich will greatly increase the versatility of the equipment.

amond compound for polishing. Shandon Scientific Co. Ltd., 6 Cromwell Place, London, S.W.7.

is diamond compound may be used for removing the ilby layer and also the relatively thick transitional zone of formed metal both of which must be removed to reveal the ie microstructure of the material in a given condition. It claimed that the compound is efficient and not expensive use. The firm also supply a dessicator capable of storing out 600 specimens with prepared surfaces.

sting sieve shaker. Endicotts (Filters) Ltd., 251 Kingston Road, Merton Park, London, S.W.19.

It is claimed that this machine is an ideal unit for the oduction of a rapid analysis of particle sizes on testing ves. It will save time in separating operations, for the erator has only to set the machine, press the time switch d record the result. The test sieves are cylindrical and are ranged coaxially, one above the other. The machine will ry seven full height and thirteen half height test sieves, or 8 in. in diameter; the sieves are carried on a rubber lined ble and are held firmly in place by a clamping plate which des up and down between two vertical rods and which n be secured at any desired height by two large wing nuts. iring use the sieve table does not rotate but is inclined to angle of approximately 15° from the vertical axis of the ichine and while this angle of tilt is constant, the direction wards which the table inclines changes progressively in a ickwise direction. Coupled with the gyratory movement the table there is an upward and downward movement at frequency approaching 300 vibrations/min at an amplitude of approximately 5/32 in. The machine is powered normally by a fractional h.p. a.c. single phase motor to work off either 200–220 or 230–250 V, 50 c/s and also has a built-in time switch which can be pre-set for tests of any duration, between 0 and 60 min, the scale being divided into 1 min intervals. The overall dimensions of the machine are 14 × 12 × 43 in., these include stand and slide rods, the total weight being approximately 1¼ cwt.

Angular displacement indicators. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

This device, known as an optical resolver, works on the following principles. If two ordinary diffraction gratings are held close together with their rulings not quite parallel, Moiré fringes are seen. If one of the gratings moves across the other in a direction perpendicular to its ruling, the fringes move up and down the ruling and can be counted as they pass. In the optical resolver, two circular gratings are used; one is fixed, and the other attached to a shaft. The angular displacement of the shaft, as it rotates, is measured by counting the fringes. To distinguish between clockwise and counter-clockwise rotation, the fringes are detected by two photo-transistors so positioned that their approximately sinusoidal outputs are roughly 90° out of phase; a discriminator in the associated circuitry accepts one phase for clockwise counting and the other for counter-clockwise. A third detector gives a "marker" signal and so provides a reference mark or zero for the scale. Consequently, the optical resolver, which gives high orders of accuracy and resolution, can be used as a pulse generator and as a direction indicator.

Thus with one detector only, it will generate pulses, and providing the shaft is going in one direction only, the number of pulses will be proportional to the angle through which the shaft is turned. Combined with a counter-clock, it can then be used for speed measurement, e.g. tachometry. With two detectors only, it will generate pulses and provide an indication of whether the pulse should be additive or subtractive. Given a reversible counter, it can show the precise position of the shaft irrespective of the direction of its rotation. With three detectors, it can measure angular displacement from a fixed zero and provide itself with a check on its counting of the two outer tracks.

The optical resolver has the important advantages of low torque (less than 1 oz/in.), small moment of inertia and long life.

Counter for adding and subtracting. Counting Instruments Ltd., 5 Elstree Way, Boreham Wood, Hertfordshire.

This counter is a self-contained unit with a four figure presentation. The number wheels are actuated by two escapement type mechanisms operated from separate d.c. or a.c. supplies. The first escapement operates to add, at the same time releasing the second, and when subtracting this operation is reversed. It is claimed that counting + or − is possible up to speeds of 17/s and the design is such that damage cannot occur if both adding and subtracting pulses are supplied at the same time.

Large figures are used in the display and all working parts are made to precise limits to ensure accuracy of count and long life. The dimensions are 2 in. long × 2¾ in. wide × 2 in. high. The figures are in white, and are 7/32 in. high by 5·4 mm wide; and the machine operates on a voltage of 24/28 V d.c. or 200/250 V a.c.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: A. S. Douglas, J. Franks, K. D. Froome, D. E. R. Godfrey, E. O. Hall, G. W. Hamstead, H. K. Henisch. S. C. Jain, W. O. Lock, S. G. G. Macdonald, G. W. A. Morris, B. G. Owen, K. I. Roulston, A. H. Ward, P. E, Watson, R. W. H. Wright.

Associates: K. H. J. Adams, K. V. Aubrey, G. S. Barlow, F. Baynes, A. C. Benson, C. E. Brindley, R. Brymner, A. C. Chapman, J. C. Cooper, C. W. Dally, B. L. Davies, V. Deshpande, R. O. W. Fletcher, I. V. Hansford, T. Hatherton, P. J. Heywood, G. Jackson, D. A. James, J. G. Jones, M. J. Jones, E. A. Kellett, W. E. Laker, B. D. Lambourn, I. G. Main, W. J. G. Massey, D. May, E. J. W. Morrison, T. R. Morgan, P. Muff, J. J. Parker, B. L. Rees, A. D. Reid, R. Riley, D. M. Roycroft, J. W. Saunders, J. Seymour, A. Shilton, A. Skertchly, E. J. Smith, W. A. Smith, Sister St. Joan of Ark, G. W. Taylor, B. J. Thompson, J. A. Wesson, D. F. White, R. C. Wratten, J. Zarzycki.

Forty-three Graduates, seventy-four Students and four Subscribers were also elected.

Australian conference on solid state physics

The Australian Branch of the Institute of Physics announces that it is arranging a conference on Solid state physics to be held from 17–24 August, 1959 in Melbourne. There will be a number of overseas visitors attending the conference.

Details may be obtained from the convener of the organizing committee, Dr. W. Boas, C.S.I.R.O., Tribophysics Laboratory, University of Melbourne, Carlton, N.3, Victoria, Australia.

Symposium on interferometry

A symposium on interferometry is to be held at the National Physical Laboratory from 9–11 June, 1959. The symposium is designed for specialists and will not deal primarily with technical applications. There will be four half-day sessions devoted to the presentation of papers and to discussion, and a fifth session for the viewing of demonstrations.

About 20 main papers have been invited and will be printed and circulated in advance. Additional short contributions will be welcomed in the form of contributions to the discussion on the main papers, or in the form of demonstrations.

Attendance is by invitation, and applications should made to Mr. L. H. McDermott at the National Physi Laboratory, Teddington, Middlesex.

Notes for prospective authors

Authors preparing contributions for submission to t *Journal* are invited to make use of the guidance available in 32-page booklet entitled *Notes on the preparation of contri tions to the Institute's Journals and other publications.* It intended to assist less-experienced authors and to serve as reference booklet for all who wish to contribute to t Institute's publications. It gives hints on the preparation scripts and diagrams, on the lay-out of mathematics for t printer, the correction of proofs and so on. In addition to short bibliography of reference books and works on techni writing, there are lists of the spellings, symbols and abbrevi tions used by the Institute. These conform with Briti Standard 1991, Part 1: 1954: *Letter symbols, signs a abbreviations*, *Part* 1, *General*, which authors of mathematic papers are also advised to consult.

Copies of the booklet may be obtained from The Institu of Physics for 2*s*. 6*d*. (including postage).

British Journal of Applied Physics

Contents of the February issue

ORIGINAL CONTRIBUTIONS

Papers

Counter diffractometer—The theory of the use of centroids of diffraction profi for high accuracy in the measurement of diffraction angles. By E. R. Pi and A. J. C. Wilson.

Effect of temperature and moisture content on the orientation produced by t drawing of nylon 66. By C. G. Cannon and F. P. Chappel.

Thermionic properties of thorium deposits on control grid materials. By J. Champion.

NEW BOOKS SECTION (containing reviews of over 40 new books)

ORIGINAL CONTRIBUTIONS (*continued*)

Method for measuring the complex dielectric constant of a high-loss liquid 8 mm wavelength. By E. H. Grant.

Linear photomultiplier bridge circuit for the measurement of small changes absorption. By P. Hariharan and M. S. Bhalla.

Deposition by thermal evaporation of thin films of titanium and zirconium f tritium targets. By V. D. Scott and L. W. Owen.

Experimental determination of the atomising efficiency of a high-speed spinni disk atomiser. D. J. Ryley.

Distribution of relaxation times in a symmetrically stressed renneted milk g By G. W. Scott Blair and J. Burnett.

Volume of drops of aqueous solutions transferred to a slide by a "micro-rod By A. E. Hawkins.

Correspondence

The problem of exo-electron emission phenomena. From B. Sujak.

NOTES AND NEWS

Notes and comments

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SPECIAL ARTICLE

Theory and design of getter-ion pumps

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The theory and design are discussed of getter-ion pumps, in which gas is exhausted by sorption in metal layers in the presence of an ionizing electron stream. The development of getter-ion pumps is traced from the early observations of gas absorption in glow-discharge tubes and sputtered and evaporated deposits. The effects of activating the residual gas by ionization are discussed and it is shown that only a limited number of gas-metal pairs are known where this enhances the sorption rate. Generally, the speeds of oxidizing reactions are not influenced by activation. Inert gases, which cannot be directly sorbed by the getter, may be ionized and their positive ions transported to a target, where they may be embedded or covered by metal films. The sorption and deposition properties of a range of getter materials are surveyed, and it is shown that titanium, barium and calcium may be used in evaporation type pumps. Methods of continuously replenishing the gettering surface by vacuum evaporation and cathodic sputtering in a range of pumps are described. The use of getter-ion pumps with mechanical and diffusion pumps for pre-exhaustion and obtaining very low pressures are discussed, and factors limiting the ultimate pressure considered. The performance of getter-ion pumps is compared with that of diffusion pumps and it is shown that getter-ion pumps may be used where the gas throughput is small, e.g. attaining *ultra high vacuum* in degassed envelopes and maintaining the vacua in electronic apparatus of limited volume.

1. INTRODUCTION

e gases and vapours in a vacuum vessel may be removed,
her by extraction with mechanical and diffusion pumps
d expelled to the atmosphere, or by trapping in the vacuum
tem by absorbent bodies and condensers. (The word
sorbent is used here in its widest sense and covers all
ption processes, whether physical or chemical in nature.)
cuum engineering has been mainly concerned with the
velopment of these two techniques which have been both
ntly and separately applied. Thus, before the advent of
ede's diffusion pump (1915) and Langmuir's vapour
eam pump (1916) it was usual to evacuate low-pressure
vices with mechanical pumps in combination with either
ters or degassed charcoal cooled to liquid air temperature.
owever, it is now general practice to use vapour stream
mps when gas is liberated rapidly in the exhausted vessel
d gas absorption devices, such as getters, where the
gassing rate is low, e.g. for maintaining the vacua in sealed-
devices which have been previously outgassed by baking.
Renewed attention has recently been given to the older
es of pumping media, i.e. gas-absorbing devices, for
taining either *ultra high vacuum* ($p < 10^{-8}$ mm of mercury)
low pressures free from contamination by hydrocarbon
pours such as those of diffusion pump fluids. The new
mping devices are based on a technique which has long
en established in the thermionic valve industry for pro-
ling and maintaining low pressures in glass envelopes, i.e.
gas-absorbing capacity of a flash getter film which is
parently enhanced by ionization of the residual gases
posed to an electron stream. High vacuum pumps, in
ich metal films are continuously evaporated, have been
veloped in America and are popularly known as "evapor-
" pumps. "Sorption" pumps have also been developed
which the absorbent film is continuously renewed by
thodic sputtering and the general term "getter-ion" pump
preferred here.

As will be shown the operation of a getter-ion pump is
mplex, even when a pure gas is exhausted, and with gas
xtures such as are present in normal vacuum vessels the
rption mechanism is incompletely understood. An appre-
ation of the principles of design and pumping characteristics of getter-ion pumps can only be obtained by studying the extensive literature on the sorption of gases in ionized atmospheres and by chemically active surfaces.

2. GAS SORPTION IN ELECTRICAL DISCHARGES

The absorption of gases in ionized atmospheres is considered here only so far as it has bearing on the operation of getter-ion pumps. Ionization pumps are known in which gas molecules are transported as positive ions to the port of a mechanical pump, but discussion of these is outside the scope of this article. The drawings shown in Fig. 1(*a*–*f*) form an historical sequence in the development of the getter-ion pump and should be studied with this section.

(*a*) *Glow discharge*

It was first observed by Plücker(1) that the gas pressure in a Geissler tube was reduced during the passage of the glow discharge. Numerous subsequent observers studied the phenomenon and discovered several mechanisms by which gas could be absorbed in discharge tubes. Thus Willows(2) and Hill(3) found that gas was absorbed during the passage of an electrodeless discharge in a glass vessel, such as in Fig. 1(*a*). Soddy and Mackenzie(4) noted that inert gas atoms were absorbed by the aluminium electrodes of a glow-discharge tube from which they could be removed by degassing. Also, inert gas atoms could be trapped in the sputtered layer on the wall, but did not apparently penetrate the glass.

The rate of gas clean-up is always greater in a tube in which the sputtering rate is high. Thus Vegard(5) found a rapid rise in the rate of gas absorption as the voltage across a tube rose above a critical value of about 500 V. The rapid rise in the absorption rate coincided with the onset of sputtering, so that a metal deposit rapidly formed on the wall of the tube as in Fig. 1(*b*). It has been shown by Güntherschulze(6) that the sputtering rate rises rapidly at applied voltages above about 500 V, because at the higher voltages the gas pressure is sufficiently reduced ($p < 0{\cdot}5$ mm of mercury) for the sputtered atoms to escape from the vicinity of the cathode and be deposited on surrounding walls.

The manner in which gas is absorbed by the sputtered metal is complex. Active gases (oxygen, nitrogen) may form compounds on the cathode which sputter without dissociation, or they may combine with the metal during deposition. Less active gases may be trapped in the condensing deposit. The latter must be an important mechanism of gas absorption, because Vegard found that during the sputtering of gold and platinum in oxygen the clean-up was greatest for gold, which was in agreement with its higher sputtering rate. However, it is now known that during sputtering, platinum more easily reacts with oxygen to form an oxide than gold, so that in this instance the trapping of gas in the growing deposit must have been the more effective clean-up mechanism. In the same way platinum was more effective than aluminium in cleaning up nitrogen because the aluminium hardly sputtered at all.

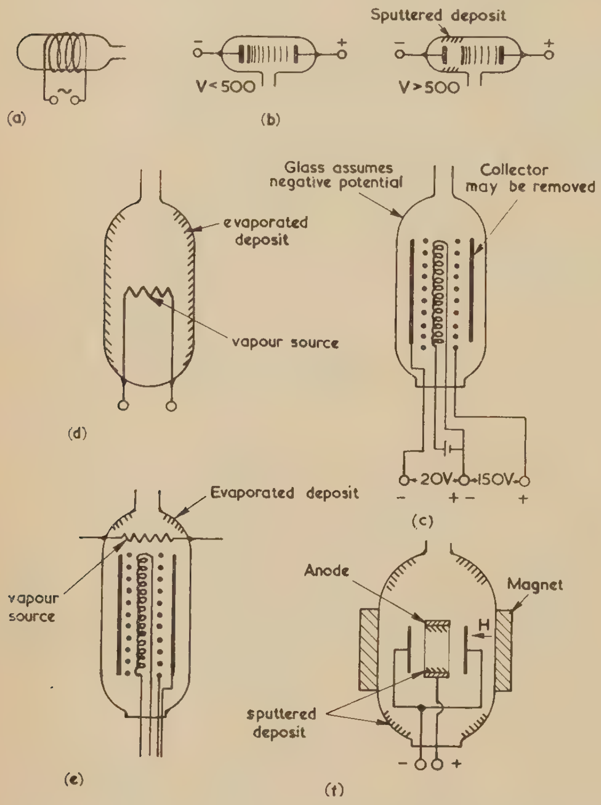


Fig. 1. Devices in which gas is cleaned up using sputtered or evaporated films in ionized atmospheres

(*a*) Electrodeless discharge; (*b*) cold cathode discharge; (*c*) ion pump; (*d*) evaporated film; (*e*) getter-ion pump; (*f*) Penning pump.

Gas may be absorbed by the discharge electrodes but this depends on their initial gas content. Thus in several of the works reviewed here the electrodes liberated gas as they became heated by the glow discharge. Since gas is sorbed mainly during sputtering or by positive ions penetrating the electrodes, the nature of the cathode metal is of greater importance than that of the anode.

Several workers have observed that electrodeless discharges in glass vessels produce optically absorbing deposits on the chamber walls, and it is possible that part of the gas sorbed in an electrodeless discharge is trapped within a film sputtered from the glass. Thus the writer(7) has observed that sodium is readily sputtered from soda lime glass bombarded by positive ions with fairly low energies (1–3 k
It is of interest to note that most workers have found th
soda glass is more effective than potash lime or lead glass
cleaning up gas.

(*b*) *Ionization gauges*

Sorption of gas also occurs in hot cathode devices, such
ionization gauges, operated under high vacuum ($p < 1\ \mu$
mercury) as shown in Fig. 1(*c*). As with a glow dischar
the clean-up of gas may arise by several processes. Mo
cules of chemically active gases such as hydrogen, oxyge
nitrogen, and certain hydrocarbons on striking the h
cathode (approximately 2300° K) may be dissociated a
thereby readily combine with the walls of the contain
Electrical clean-up of gases occurs when the accelerati
potentials are applied to the ionization gauge electrod
Schwarz(8, 9) and others have shown that the positive io
formed by electron impact are driven into the negative
charged surfaces of the gauge where they are neutralized a
trapped. Koch(10) has, in fact, collected the isotopes
inert gas ions by bombarding metal targets in a mass spect
meter. The gases could be subsequently liberated in seale
off tubes by baking the metal.

The glass walls of an ionization gauge exposed to electr
bombardment assume a negative potential because the
secondary electron emission is less than unity at the potentia
used. Positive ions are attracted to the negative walls ar
any neutralization of the surface charge is quickly destroye
by the intense electron stream. Schwarz has indicated th
glass is more efficient than metals for absorbing positive ion
Alpert(11) has used these techniques for the attainment
pressures of 10^{-9} to 10^{-11} mm of mercury, generally terme
"ultra high vacuum." The pumping action of the gla
walls of an ionization gauge has been confirmed by Young
and Comsa and Musa(13) have described an ionization pu
in which there is no positive ion collector except the gla
walls.

Some difficulty has been experienced in attributing th
clean-up of helium to absorption by the glass envelo
because of the readiness with which helium is known
diffuse through glass. Varnerin and Carmichael(14) hav
indicated that the helium ions are trapped in a metal fil
on the glass walls which evaporates from the gauge electrod
during the degassing cycle. Fast(15) has stated that heliu
is not dissolved by metals. Thus if the helium ions bomba
the walls, then presumably they must pass through the met
layer and become sandwiched between glass and coatin
and unable to diffuse back.

Gas is absorbed when a Penning ionization gauge
operated, as noted by Penning.(16, 17) The clean-up of ga
occurs in the several ways outlined above, but the mos
effective source of gas absorption is sputtering. The write
has noted that even aluminium electrodes which sputte
slowly have a sufficient rate of disintegration at low pressure
to give an appreciable pumping speed.

(*c*) *Getter films and electrical discharges*

The gas pressure in a vessel, as shown in Fig. 1(*d*), may b
reduced by evaporating chemically active materials (usual
metals) which combine with the residual gas. When th
gas pressure is of the order of 0·1 μ of mercury there ar
limited collisions between vapour and gas atoms in spac
but the molecules of the reactants may combine rapidly
the receiver surface on which they simultaneously imping
The pressure may rise during evaporation if the evapora
has not been degassed or contains gases only liberated at th

oration temperature. Slow evaporation produces the est gas absorption in the growing deposit, so that the pressure may fall even though gas is liberated from evaporant. Clean-up of gases occurring during deposi- of the getter is known as "dispersal" gettering, whereas due to reaction between the gas and the fresh surface condensed film is known as "contact" gettering.

lean-up by contact gettering may occur by a variety of esses involving physical (van der Waals) adsorption; vated adsorption (i.e. chemisorption); chemical com- tion; adsorption and solution in the solid. Inert gas ecules can only be held to surfaces by van der Waals rption, which is not an effective source of clean-up at nal temperature.

oddy(18) was one of the first to study and apply the tion properties of evaporated metal films. He sublimated um at low pressures and found that the chemically e gases were removed from the residual air leaving n in a purified state. He constructed an early form of r pump using calcium, and avoided the presence of lual argon by initially substituting the air in the vessel e evacuated by a chemically active gas. Clough(19) rved that calcium, titanium and magnesium were very tive metals for purifying inert gases and evaporated by means of an electrical arc at low pressures. kay(20) considered that there was evidence that the tion was not a purely chemical one and that the arc vated the gaseous impurities so that they combined more ily with the metal vapour.

ukirsky and Ptizyn(21) observed that the sorption rate of nesium for nitrogen could be raised by ionizing the gas an electron current. The effect was also investigated Reimann,(22) who showed that magnesium cleaned up rogen faster when it was atomized by colliding with an ndescent tungsten filament or a heated oxide cathode. nann found that passage of an electron current only lerated the clean-up when the anode voltage was above required to form H_2^+ ions. This suggested that the anced absorption was due to the transporting of positive to the getter surface, but calculation showed that the ease in the clean-up was greater than that derived from positive ion current flowing to the getter. Reimann found atomic hydrogen was formed during the neutralizing of H_2^+ ion and the atomic gas, irrespective of where it had formed in the tube, was quickly absorbed by the gnesium.

a later paper Reimann(23) reported that the sorption of oon monoxide by magnesium in the presence of an zing current was merely increased by the number of itive ions reaching the getter surface. It was not possible ind the effect on the sorption rate of metastable carbon noxide molecules, because at the high pressure at which were produced the contact gettering of ordinary carbon noxide was too great. Many workers believe that the ctiveness of a getter in maintaining the vacuum in a mionic valve arises from activation of the gas by the tron stream. Thus, in that sense, a thermionic valve is a er-ion pump such as is shown in Fig. 1(*e*).

Vagener(24) studied the effects of an ionized atmosphere the clean-up rate of barium for oxygen, nitrogen, carbon noxide, carbon dioxide and water vapour. He found in h case a dependence of the gettering rate on the electron rent, and believed that the gettering was almost entirely to the take-up of atoms or metastable molecules produced impact of the electron stream on the gas molecules. sequently he repeated part of this work using a Knudsen manometer in place of an ionization gauge for measuring the pressure in the getter chamber. Wagener(25) then reported that the rate of clean-up of oxygen and carbon monoxide by barium was unaffected by ionization of either gas, but was increased with carbon monoxide and magnesium. Bloomer(26) studied the clean-up of oxygen by barium using a Pirani gauge for pressure measurement as employed by Reimann. He found that an ionizing electron current had little effect on the rate of clean-up, but that the gettering rate of a used film could be increased if the gas molecules collided with a heated tungsten filament. Bloomer(27) also found that an ionizing discharge had little influence on the rate of clean-up of barium for carbon monoxide when the film was above or below the minimum temperature (80° C) for continuous gas sorption. The high sorption rates initially measured by Wagener could have been due to the film temperature not being controlled during the experiment.

Dravnieks(28, 29) found almost no difference in the oxidation rate when either activated or ordinary oxygen at a pressure of 0·5 mm of mercury was used with tantalum, zirconium, nickel and copper at 500–690° C. Tests made at 986° C with water vapour, carbon dioxide and carbon monoxide at $p = 0{\cdot}3$–$0{\cdot}6$ mm of mercury showed that the attack by ionized carbon dioxide was slightly stronger, whilst that by water vapour and carbon monoxide was less than the attack by the normal gases. When a chemical reaction proceeds by diffusion through a surface skin it is unlikely that activation of the gas will increase the clean-up rate. If, however, a gas is cleaned up as a chemisorbed layer of atoms then ionization and dissociation of the gas may increase the sorption rate.

3. PROPERTIES OF GETTER MATERIALS

Types of getter. Getters are normally used either in the form of thin films or metal ribbons and powders, which are referred to here as solid getters. Metal films prepared by vacuum evaporation generally clean up gases rapidly at normal temperature because of the freshness of their surfaces. Evaporated films also possess a large surface area due to their granular structure, and adsorbed gas molecules migrate to the interior of a film along the grain boundaries, thereby maintaining the sorption rate for an appreciable period.(30, 31) The clean-up rate of a solid getter quickly decays as its more limited surface becomes covered with gas molecules. Thus, solid getters are usually operated at high temperatures to aid diffusion of the adsorbed gas into the solid. It is of interest to note that Haine, Francis and Bloomer(32) were able to obtain periodically the high sorption rate of a clean titanium surface by abrading the metal sheet in a vacuum with a file to remove protective surface compounds.

Useful metals. Thin film getters are usually chosen from the alkaline earth metals barium, strontium, calcium and magnesium, because of their chemical activity and the relative ease with which they can be volatilized in a vacuum. Solid getters are normally selected from the transition elements of the fourth to sixth groups, namely titanium, zirconium, hafnium, tantalum, molybdenum, tungsten, as well as thorium and uranium, because of their chemical activity and their high sorption capacity when used in thermionic valves operated at high temperatures. Barium films may be used at temperatures up to 400° C without evolution of sorbed gas. The alkaline earth metals form compounds which are loosely bonded to the underlying metal and, if used as solid getters, the thick surface coatings would flake off at high temperature. Vacuum pumps using solid getters can be made for maintaining the vacuum in magnetrons, etc., but the present development of the getter pump as a definite unit is based on the use of metal films which are continuously deposited as discussed in the next section.

Presented in Table 1 is a list of well-known metal getters with data on their initial adsorption rate and sorptive capacity (see Appendix) and the influence of activation of the gas on the clean-up rate. Perusal of Table 1 shows that the only metals which clean up a range of gases and have sufficient volatility to be readily prepared in thin film form, are barium, calcium and titanium. Metals which are difficult to evaporate may be sputtered and can be used in Penning ionization pumps as described in Section 4.

Film structure. The adsorptive capacity of a thin metal film depends upon its surface area, which in turn depends upon the roughness and size of the crystallites in its structure. Numerous investigations of the structure of thin films have shown that a microcrystalline structure is formed when the film atoms are unable to migrate on the substrate during the initial stages of condensation, or when the deposition rate is high so that many nuclei are simultaneously formed. Migration of the film atoms will be least the lower the condensation temperature and the greater the affinity between the film and substrate atoms. If appreciable aggregation of the film nuclei occurs, the outer surface of a coating on glass may become sufficiently rough to reflect diffusely incident light, but the actual adsorptive capacity of the film may decrease because fewer of the film atoms are in the crystallite surfaces.

Generally, the adsorptive capacity of an evaporated film has been shown to increase with the melting point of the metal, and it has been argued that the surface atoms of low m.p. metals are more mobile and give rise to relatively smooth surfaces of small area.(41) However, this cannot be the only factor determining the surface area of a film. Thus Wagener(30) has found that barium with its low melting point adsorbed larger quantities of carbon monoxide than titanium and molybdenum. A low melting point metal may form a fine crystalline structure if the atoms cannot migrate on the substrate during nuclei formation. Thus aluminium (m.p. = 660° C) forms a micro-crystalline film on glass and resists aggregation at temperatures up to 400° C, whereas silver (m.p. = 961° C), because of its poor affinity to glass, produces films with larger crystallites which readily grow to form spherical droplets when heated to 300° C. The influence of the substrate material on the adsorptive capacity of a superimposed film has apparently not been studied, and it may be one of many reasons for the lack of agreement in the measured values of given film and gas pairs. Most workers propose that metal films should be deposited on a cold substrate to obtain a micro-crystalline structure, and that the film should be heated afterwards if a high temperature is necessary to ensure a given chemical reaction proceeds without decay. The effect of the temperature rise on the film structure will depend in a complex way on the affinity of the film material to the base and the atomic mobility of the film atoms in the crystallites.

Contact getters of large surface area may be produced by evaporating at high pressures in impure inert gases; such deposits are grey to black in colour and contain minute amounts of oxide in their structure. Black deposits are highly porous and nearly all of the film atoms are concentrated at the surface. Such coatings cannot be used in a getter-ion pump where the getter is periodically replenished by evaporation at low pressures.

Metal films deposited at high incidence angles form rough surfaces because the vapour atoms preferentially condense on the more prominent nuclei. Deposits of this kind invariably formed in getter-ion pumps and their sorp properties have not been studied. Likewise there is information on the adsorptive capacity of films deposite layers which have previously been gas contaminated.

Sorption of different gases. The residual gas in non-ba vacuum systems constructed from glass or metal is usu made up of water and hydrocarbon vapours, and di from that evolved in degassed and sealed-off envelopes, as thermionic valves, where the principal gases evolved usually hydrogen and carbon monoxide. There is siderable literature on the sorption properties of g materials for the latter gases but there is little data on clean-up of water vapour. The writer has found du dispersal gettering that both aluminium and titanium r with water vapour to form oxides and liberate hydro When the pressure is high (greater than $0 \cdot 05\ \mu$ of merc the hydrogen is not readily absorbed by the oxide- taminated deposit. However, if the gettering is done wi diffusion pump in operation, there is an apparent r clean-up due to the high pumping speed of the diffu pump for hydrogen. Barium, on the contrary, readily cl up water vapour as shown by Della Porta.(37)

Most getters clean up gases by chemisorption at r temperature, and Trapnell(35) has found that there i definite order of affinities of gases common to all m surfaces and for those tested by him this order was

$$O_2 > C_2H_2 > C_2H_4 > CO > H_2 \geq N_2$$

If a metal chemisorbs a particular gas it will also chemis all gases higher in the scale, but if it does not then gases not chemisorbed lower in the scale. Trapnell states ordinary chemical reactivity between a gas and a meta no guide to activity in chemisorption. Thus alumin does not chemisorb nitrogen, although it readily form nitride.

The sorption of oxygen usually proceeds as a chem reaction at the getter surface but oxygen rarely exists i free state in the residual gas of a vacuum system. The o coating which forms on the alkaline earth metals is protec at normal temperatures, and continuous growth only occ when the temperature is raised and the oxide film cra The specific oxides of this group occupy a smaller vol than the metal which they contain, so that the protec film is inherently unstable. Thus thin barium films oxid right through at temperatures above 40° C,(26) but it is clear whether this is due to fracture of the oxide or m rapid growth through a protective film.(42) Continu growth is only obtained with magnesium and calcium high temperatures, as shown in Table 1. The transit metals form oxide films which quickly grow to a limit thickness, and they must be raised to a high temperat before oxygen is continuously sorbed.

Oxide coatings may bar the sorption of other gases. T Stout and Gibbons(34) found that hydrogen was absor by clean titanium at room temperatures but oxide-coa metal did not absorb hydrogen below 300° C. Bloomer noted that barium reacted with carbon monoxide to fo an oxide and free carbon, but below 80° C the reaction limited by a surface oxide film.

Most workers have found that the rate of adsorption nitrogen by barium is low at normal temperature. Sasaki observed that from 50 to 100° C the nitrogen was chemisor to the barium surface, and above 100° C the barium chemica reacted to form a product of the approximate form Ba_3 During the early stages of the chemisorption of nitrogen

Table 1. *Some characteristics of metal films of importance in determining their usefulness as getters*

C = chemical reaction. *Ch* = chemisorption. *D* = diffusion. *L* = linear law of oxidation.

Getter film	*Gas*	*Initial adsorption rate* ($\simeq$20° C) ($-s^{-1}\ cm^{-2}$)*	*Film temperature for continuous sorption* (° C)	*Sorptive capacity* $l\mu/mg$ (T° C)†	*Adsorption rate enhanced by ionization*	*Reference*	*Remarks*
inium	O_2	*C*	500°	7·5–38·5 (20)	—	33, 58	—
= 660° C	H_2	0·0	—	0	—	33	
C (v.p. = 100 μ)	N_2	0·0	—	0	—	33	
	CO_2	<0·005 *l.*	—	0	—	33, 36	
	CO	<0·005 *l.*	—	—	—	36	
um	Air	*Ch*	—	56 (400)	—	37	H_2 gettering increased by presence of heated cathode. Commercially available metal requires extensive degassing or distillation to remove impurities. Can be obtained in alloy form with Al.
= 717° C	O_2	0·3 *l.*	>40°	57 (300)	No	24, 25, 26, 33, 36, 37, 42	
C (v.p. = 100 μ)	H_2	0·05 *l.*	200°	100 (400)	No	24, 33, 36, 37 60	
	H_2O	*C*	—	72 (300)	—	37	
	N_2	0·003 *l.*	>100°	{3–25 (<100) 43–51 (>100)}	Yes	24, 31, 33, 36, 37, 38, 60	
	CO_2	5·0 *l.*	—	66 (400)	—	24, 33, 36, 37	
	CO	3·5 *l.*	>80°	100 (400)	No	25, 27, 30, 37	
	C_2H_2, C_2H_4	*Ch*	—	—	—	35	
um	O_2	*C*	425° L	—	—	18, 35	Electrolytically prepared metal may contain CaH_2 which dissociates at the evaporation temperature. Distilled metal is commercially available and cheaper than Ba.
= 810° C	H_2, N_2, CO, C_2H_2	*Ch*	—	—	—	18, 35	
C (v.p. = 100 μ)	CO_2, H_2O, SO_2, NH_3	*Ch*	—	—	—	18	
	C_2H_4	*Ch*	—	—	—	35	
nesium	O_2	*C*	>450° L	20–200 (20)	—	33	H_2 gettering increased by presence of heated cathode.
= 651° C	H_2	0·0	—	—	Yes	22, 33	
C (v.p. = 100 μ)	N_2	0·0	—	—	—	33	
	CO_2	<0·005 *l.*	—	—	—	33, 36	
	CO	<0·005 *l.*	—	$\simeq$0·0 (30)	Yes	25, 36	
ium	O_2	*C*	—	—	—	39, 40	Vacuum-melted metal in form of wire and sheet is commercially obtain able, contains $\simeq$0·008% of H_2.
= 1660° C	H_2	*Ch*	—	—	—	30, 39, 40	
C (v.p. = 100 μ)	N_2	3·0 *l.*	—	1·9–2·5 (30–300)	—	30, 39, 40	
	CO_2	4·3 *l.*	—	4·3 (20)	—	30, 39, 40	
	CO	12·0 *l.*	—	3·4–4·2 (30–200)	—	30	
	SF_6	*Ch*	—	—	—	39, 40	
	C_2H_2	*Ch*	—	—	—	35	
	C_2H_4, CH_4, CCl_2F_2, NH_3	*Ch*	—	—	—	39	
ium (solid)	O_2	2·01 *l*μ (800°)	>650° L	90 (800)	—	34	CH_4 dissociates when striking Ti at 1200° C, C is sorbed and H_2 taken up at lower temperature. H_2 is only gas released by heating. Surface oxide reduces H_2 sorption below 300° C.
	H_2	*D*	20°–400°	—	—	34	
	N_2	0·08 *l*μ (1000°)	>700°	160 (1000)	—	34	
	CO_2	0·81 *l*μ (1100°)	>700°	50 (1100)	—	34	
	H_2O	*D*	300°–400°	—	—	34	
onium	O_2	*C*	—	—	—	35	
= 2127° C	H_2, C_2H_2,C_2H_4	*Ch*	—	—	—	35	
° C (v.p. = 100 μ)	N_2, CO	>2·5 *l.*	—	—	—	30	
onium (ribbon)	O_2	*C*	885°	1·99 (400)	No	28, 29, 33, 62	
	H_2	*D*	300°–400°	13·3 (350)	—	33, 62	
	N_2	*C*	1527°	1·46 (800)	—	33, 62	
	CO_2	*C*	—	3·04 (800)	Yes	28, 29, 33, 62	
	CO	*C*	—	3·65 (800)	No	28, 29, 33, 62	
alum	O_2	*C*	—	—	No	28, 29	Difficult to evaporate—low vapour pressure.
= 2996° C	H_2, C_2H_2, C_2H_4	*Ch*	—	—	—	35	
° C (v.p. = 1 μ)	N_2	>2·5 *l.*	—	—	—	30	
	CO	>2·5 *l.*	—	—	No	28, 29, 30	
ybdenum	O_2	*C*	—	—	—	35	Difficult to evaporate thick films—low vapour pressure. May be sublimated.
= 2622° C	H_2, C_2H_2, C_2H_4	*Ch*	—	—	—	35	
° C (v.p. = 10 μ)	N_2	2·7 *l.*	—	1·0 (30)	—	30	
	CO	3·5 *l.*	—	3·0 (30–200)	—	30	
gsten	O_2	*Ch*	—	—	—	35	Difficult to evaporate thick films—low vapour pressure. May be sublimated.
= 3382° C	H_2, C_2H_2, C_2H_4	*Ch*	—	—	—	35	
° C (v.p. = 10 μ)	N_2, CO	>2·5 *l.*	—	—	—	30	
rium	O_2	*C*	450° L	7·5–33·1 (20)	—	33	Difficult to evaporate—low vapour pressure.
= 1827° C	H_2	*Ch*	—	19·5–53·7 (20)	—	33	
° C (v.p. = 100 μ)	CO_2	*Ch*	650°	—	—	33	
nium	O_2	*C*	240° L	10·6–9·3 (20)	—	33	
= 1132° C							
° C (v.p. = 100 μ)	H_2	*Ch*	—	8·9–21·5 (20)	—	33	
h metal	O_2	*C*	—	21·7–51 (20)	—	33	Chiefly cerium and lanthanum.
um	H_2	*Ch*	—	46·1–64 (20)	—	33	
= 785° C	N_2	*Ch*	—	3·2–16 (20)	—	33	
° C (v.p. = 100 μ)	CO_2	*Ch*	—	2·2–45 (20)	—	33	

* Initial adsorption rates are given in terms of volumetric and mass speeds (i.e. $l\ s^{-1}\ cm^{-2}$ and $l\mu s^{-1}\ cm^{-2}$) according to author.

† Generally values are for bright films, where two values are quoted the second figure is for a black deposit.

adsorbed gas could be expelled by oxygen when this was admitted to the vessel.

Material purity. The nature of the impurities in the getter material are of importance, because gas may be evolved during evaporation and thereby lower the sorptive capacity of the deposit. Soddy(18) in his early work noted that calcium may contain an hydride which dissociates during evaporation and cannot be removed by degassing at lower temperatures. Wagener and Marth(43) have shown that commercial barium getters degassed at 900° C release mainly hydrogen, water vapour and carbon monoxide.

Barium oxide can readily be reduced by aluminium, and alloys containing 36% barium have been made in this way. Barium aluminium alloys, e.g. the intermetallic compound $BaAl_4$, are used as getters in thermionic valves because an aluminium oxide film preferentially forms on the alloy surface protecting it against chemical reaction when exposed to the atmosphere.

Argon has been found in the residual gas after evaporation of barium(43, 44) and tantalum(43) suggesting that the gas had previously been trapped in the getter during its manufacture.

Commercial titanium wire drawn from vacuum-melted metal usually contains about 0·008% of hydrogen by weight which, unless removed by degassing, would give rise to a large volume of gas during evaporation, i.e. 650×10^3 litres of gas per gramme of titanium at 10^{-6} mm of mercury! Wagener and Marth found that hydrogen and water vapour were predominantly evolved when titanium was degassed at 1100° C.

4. DESIGN OF GETTER-ION PUMPS

The getter-ion pump has emerged as a definite pumping unit over the last five years. Various designs have been reported, some of which are notable both for their novelty and useful application. Thus getter-ion pumps have been devised for exhausting particle accelerators and maintaining the vacuum in magnetrons and klystrons. The design and performance of a range of such pumps are discussed below.

(*a*) *Continuous evaporation titanium pump*

Herb and others(39) have used a novel type of getter pump with a fairly large throughput for evacuating a high-voltage electrostatic accelerator in place of a diffusion pump. In their first pump a titanium getter was evaporated by feeding titanium wire on to a resistance heated carbon boat, but in a later model(40, 45) the titanium was fed on to an incandescent carbon post heated by electron bombardment as shown in Fig. 2. (This pump is marketed in America by the Consolidated Vacuum Corp. and known as the Evapor-ion pump.) With the latter apparatus it was possible to achieve a titanium evaporation rate of 1·4 mg/min for some seven days before the cathode filament failed. Titanium readily combines with carbon to form a carbide, and more recently a tantalum–tungsten alloy has been used for the anode with a slight improvement in the post life.

The inert gases which are not contact-gettered by the titanium are removed by ionization pumping with the electrode arrangement shown in Fig. 2. Positive ions of the inert gases strike the chamber walls and are either plastered over by the condensing metal or embedded in the metal surface. The pump is operated by evaporating titanium until the desired gas pressure has been reached and then maintaining the pressure by ionization pumping. As the titanium becomes covered by adsorbed gas the pumping speed diminishes and the pressure rises in the exhau vessel. A fresh titanium layer is then evaporated to res the vacuum. Given in Table 2 are the pumping sp obtained with a Herb getter pump as reported by Swartz the original pumping speeds quoted by the inventors(45) high because they did not allow for the admittance of pumping port.

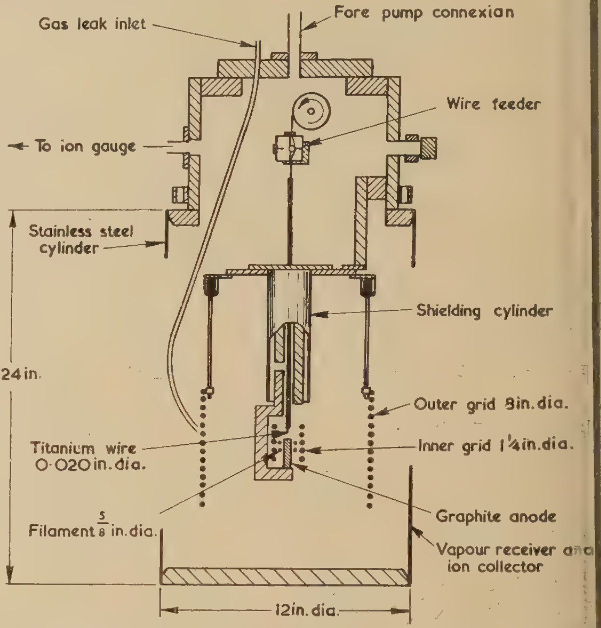


Fig. 2. Evapor-ion pump (after Davis and Divatia(45))

Wall temperature. It is essential to cool the wall of vessel during pumping otherwise the sorbed gases are relea by the deposit, as shown by the fall in the pumping sp with temperature rise in Fig. 3. The ease with which ga released by the growing deposit when its temperature ri is difficult to explain for oxygen and nitrogen, because b of these gases readily form compounds with titanium a have been identified in the structure of evaporated fil Hydrogen and water vapour will be evolved during titanium evaporation, and it is possible that the other ga are cleaned up in preference to these as the wall temperat rises. Thus there would not be a true fall in speed for pumped gases but a rise in the ultimate pressure of the pu during their admission.

The writer and his colleagues have confirmed the need cooling the receiver walls. Thus when the rate of evaporati in an 18 in. diameter vessel exceeded some 300 mg/min titanium, the pumping speed passed through a maximu and then decreased as the deposit became overheated by h radiation from the vapour source and the energy libera by the condensing vapour. The granular nature of the g contaminated deposit decreases its heat conductivity and outer layer of the film becomes hotter as it grows in thickne

Residual gases. Swartz(46) has reported that hydrog and water vapour are the most abundant gases in the atm sphere of a Herb pump during the early stages of exhaustio He also claimed that water vapour was pumped with di culty. Shown in Fig. 4 is the mass spectrum of the residu gases which was obtained at a pressure of 2×10^{-6} mm mercury. The peaks at mass to electronic charge values 15 and 16 were attributed to methane and fractions of organic contaminant. Reich and Nöller(47) have studied t mass spectrum obtained in a glass pump in which the titaniu

Table 2. Comparison of the pumping speeds of different types of getter-ion pumps*

Designer	Type of pump	External dimensions (in) diameter	External dimensions (in) depth	Pumping speed* (l/s) Air	Oxygen	Nitrogen	Hydrogen	Argon
Davis and Divatia[45] Swartz[46]	Continuous titanium feed (5 mg/min) and triode ionization pump	12	24	370(10^{-5})	1000(10^{-5})	2000(3×10^{-6})	3300(10^{-6})	5(5×10^{-5})
Huber and Warnecke[53]	Triode ionization pump with titanium grid	3	12	6–12(10^{-6})	—	—	—	—
Gale[54]	Penning gauge and titanium evaporation chamber	3	6	0·016	0·28	0·18	—	0·009(He)
Turnbull[56]	Penning gauge with combined titanium evaporation element and cold cathode	12	2	—	—	1600(5×10^{-6})	—	—
Hall[57]	Penning gauge with titanium cold cathode	3	1	10·5(10^{-7})	—	—	11·5(2×10^{-7})	9(2×10^{-7})
Cloud, Beckman and Trump[60]†	Penning gauge with barium evaporation chamber	4½	10	6–9	120–220	17	140	0·2
Edwards F1203	Fractionating oil diffusion pump	12	30	2700	2700	2700	3200	≃ 2500
Edwards F203	Fractionating oil diffusion pump	2¼	16⅜	70	70	70	100	≃ 50

* With the exception of the Davis and Divatia and Hall type pumps, the pumping speeds are the initial values for freshly evaporated deposits and not for a continuously growing layer. The gas is ionized in all cases and the pressure during measurement given in brackets in mm of mercury when reported.

† The initial pumping speed is claimed to be independent of pressure but decreases with mass of gas cleaned up.

was evaporated from a tungsten filament. They found that there was a high partial pressure of methane which was attributed to reaction between carbon and hydrogen containing gases on the getter surface. Low ultimate pressures (10^{-9} mm of mercury) could be obtained after baking the titanium pump and pre-pumping to 10^{-7} mm of mercury using a mercury diffusion pump and liquid air trap. The

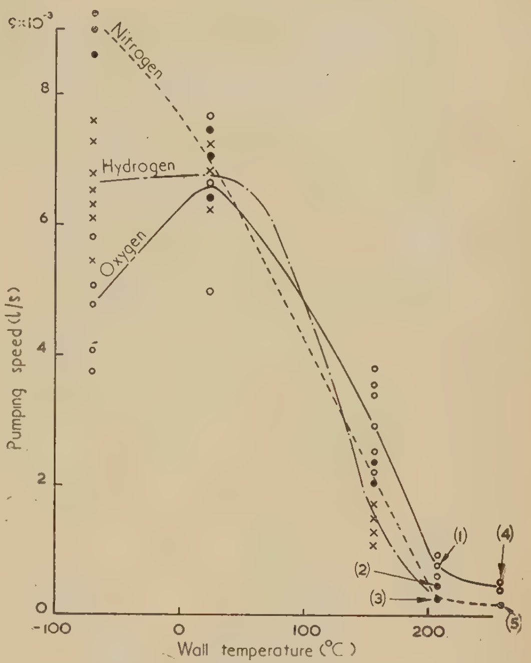


Fig. 3. Pumping speed as a function of the temperature of the gettering surface for hydrogen, nitrogen and oxygen (after Davis and Divatia[45])

Titanium evaporation rate = 7 mg/min.
Hydrogen: $p = 3 \times 10^{-6}$ mm of mercury; nitrogen and oxygen: $p = 1{\cdot}5 \times 10^{-6}$ mm of mercury.

(1) $p = 5 \times 10^{-5}$ mm of mercury.
(2) $p = 1 \times 10^{-4}$ mm of mercury.
(3) $p = 5 \times 10^{-5}$ mm of mercury.
(4) $p = 1 \times 10^{-4}$ mm of mercury.
(5) $p = 1{\cdot}5 \times 10^{-4}$ mm of mercury.

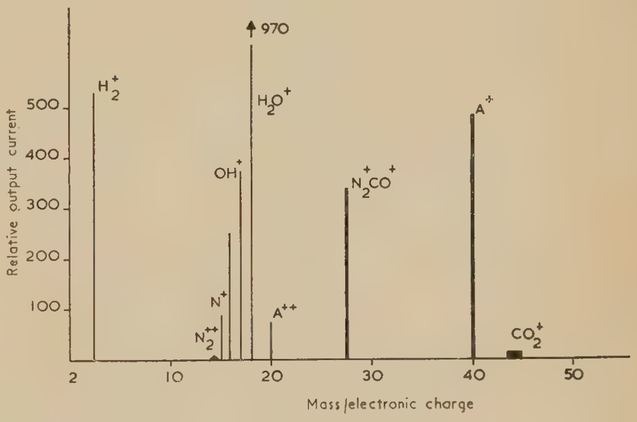


Fig. 4. Mass spectrum of gases in Evapor-ion pump during pump-down (after Swartz[46])

Total pressure (air calibration) = 2×10^{-6} mm of mercury.

residual gases then contained mainly methane and argon which had been released by the vapour source and glass walls.

Attempts have been made to explain the sorption mechanism during evaporation by determining either the numbers of molecules cleaned up per getter atom, or the probability of capture of an impinging gas molecule. It is extremely difficult to obtain data which can be used in this way because the evaporation rarely proceeds at a constant rate, also the surface area and structure of the deposit vary considerably with the support finish and evaporation conditions. However, such measurements do give *average* figures which are valuable in assessing the efficiency of a given pump. For example, the probability of capture of an hydrogen molecule in the Herb pump is 0·03 at 10^{-6} mm of mercury.(45)

Vapour sources. The anode post in the Herb pump has a limited life due to reaction with the titanium, and attention has been given to a type of vapour source in which chemical reaction is avoided by directly evaporating from the end of a wire fed into an electron beam.(48) Milleron(49) has described a titanium vapour source in which a molten bead is formed on the end of a wire fed upwards into an electron beam, as shown in Fig. 5(*a*). The writer and his colleagues discontinued work on a similar apparatus because the viscosity of the titanium was greatly reduced at the evaporation te perature (approximately 2000° C) and liquid metal r backwards and blocked the feed tube. Greater success w obtained by feeding a wire downwards into an electron bea so that a molten globule formed at the tip of the wi However, it was difficult to obtain a temperature above t melting point (1660° C) because increase in the electr stream intensity merely caused the metal to melt farther the wire. Thus with a 1 mm diameter wire a droplet of 5 m maximum diameter could be supported giving a maximu evaporation rate of 15 mg/min at the melting point.

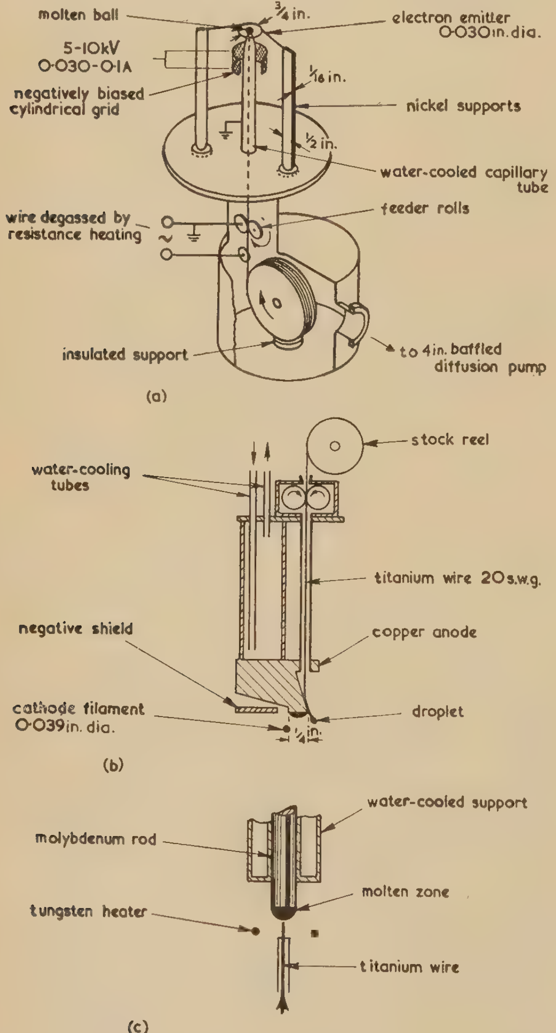


Fig. 5. Titanium getter pump vapour sources [(*a*) after Milleron;(49) (*b*) after Holland, Laurenson and Holden(50); (*c*) after Winogradoff(52)]

The writer and his co-workers(50, 51) were able to obta stable evaporation conditions by allowing the molten glob to run back along the wire and contact a water-cooled copp block. A hemi-spherical globule was then formed whi hung from a frozen zone adhering to the cooled surface in Fig. 5(*b*). Large titanium droplets of 5 mm or more diameter could be supported with their lower tip at a te perature of about 2000° C giving evaporation rates of abo 100 mg/min for a power input of 1200 W. The lifetime this vapour source was only limited by that of the catho filament which was eroded by bombardment of positive io

Winogradoff(52) has described a titanium vapour source which wire is fed upwards on to the molten tip of a moly denum rod heated by electron bombardment as in Fig. 5(Feeding metal upwards on to a heated surface is diffic because the feed tube obstructs the emitted vapour and t wire may melt back when approaching the hot zone.

Safe working pressure. The ionization source in the He pump is constructed as shown in Fig. 2. Positive gri surround the cathode filament, and the chamber wall is at negative potential so that it serves as a positive ion collec When the pressure is above 0·1 μ of mercury the pump wa operates as a cold cathode for a glow discharge, which partially maintained by the ionizing current from the h cathode. The glow discharge removes gas from the pum wall and reduces the electron current flowing to the evapora Thus with this arrangement the pump can only be broug into operation at fairly reduced pressures. Davis and Divat obtained a safe starting pressure (0·05 μ of mercury) by fir roughing with a rotary mechanical pump and then evaporati titanium getters from resistance-heated tungsten filament Some workers have used a combined Roots blower an mechanical oil pump for rough pumping the Herb pump.

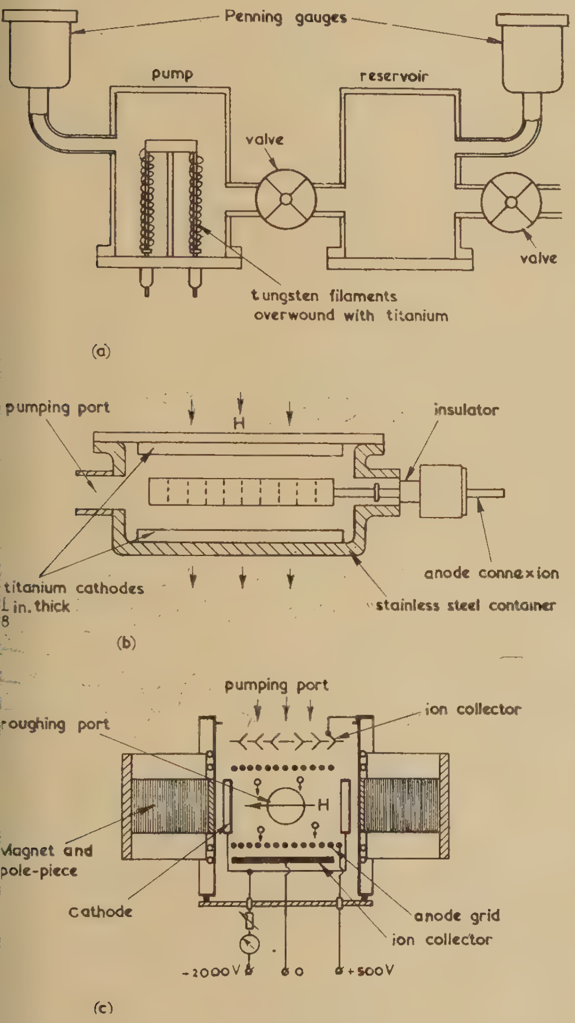
Holland, Laurenson and Holden(50) avoided unstab operation by putting the pump wall at a positive potential a gas pressures above 0·1 μ of mercury. The pump the functions solely as an absorber of chemically active gase It is unwise to operate an electron bombarded vapour sourc above 0·1 μ of mercury for long periods because the hc cathode is eroded by positive ion bombardment. A sma diffusion pump is preferable for pre-pumping down to 0·5 of mercury, since it is less expensive than a Roots blower an the vapour pressure of a diffusion pump fluid is less tha that of the lubricating oil used in mechanical pumps.

(*b*) *Titanium triode pump*

Huber and Warnecke(53) have described a getter-ion pum suitable for maintaining the vacuum in a klystron in whic the anode grid of a triode as shown in Fig. 1(*d*) was mad from a tungsten wire overwound with titanium and tungste wire along its length. After fusion the titanium was con tinuously deposited on the chamber walls, which also serve as the positive ion collector of the ionization pump. Dimen sions and pumping speed of the triode pump are given i Table 2.

(c) *Penning ionization pumps*

ale(54) has described a simple type of getter pump in ch titanium is evaporated from tungsten spiral, and the zation carried out by a Penning gauge as shown in 6(*a*). Gale found that the Penning gauge did not have e part of the evaporation vessel to be effective in increasing gettering action, which suggested that its chief role was creation of atomic or metastable molecules. Presumably, inert gases would be pumped by embedding positive ions he gauge electrodes.



ig. 6. Penning ionization pump [(*a*) after Gale;(54) (*b*) after Hall;(57) (*c*) after Von Ardenne(59)]

Gurewitsch and Westendorp(55) have raised the sorption e of a Penning gauge by fitting it with carbon or titanium iodes, which absorb gas by positive ions penetrating their faces, and also by sputtering.

Turnbull(56) has described a getter-ion pump for eva-ting radio-frequency valves in which the cathode of a ining gauge was made from a tungsten filament over-und with titanium. The titanium could be evaporated en desired to deposit a coating on the anode electrodes. nbull noted that the pumping speed for nitrogen, after poration of a fresh layer and with the Penning discharge operation, was greater than the combined speeds of the ization pump and getter film measured separately. This indicated that the clean-up was influenced by activation of the gas molecules. Presumably, gas absorbed by the cold cathode would be released when the cathode was heated to evaporate the titanium.

Hall(57) has made a Penning ionization pump in which titanium was sputtered on to a grid-shaped anode as shown in Fig. 6(*b*). (This pump has become popularly known as the Varian pump after its manufacturers, Varian Associates, California.) The active gases were pumped by reaction with the sputtered metal, but inert gases could only be pumped by either being embedded in the cathode electrodes or covered over by the sputtered deposit on the anode. However, since the cathode is continuously sputtered some of the embedded gas must be constantly liberated, and this would probably limit the ultimate pressure obtainable. Brown and Leck(58) have studied the desorption of active and inert gases from the cathodes in a Penning ionization gauge. They noted that incident ions liberated molecules previously trapped by ion bombardment of the surface and were themselves adsorbed. Because the sorption-desorption process did not depend on the nature of the gas, Brown and Leck considered it arose from physical adsorption. This could not explain the sorption-desorption of an inert gas such as argon which would not be physically adsorbed at normal temperature. It is likely that Brown and Leck were observing the liberation of absorbed gas due to sputtering of the cathode.

Von Ardenne(59) has described a Penning type pump in which titanium is sputtered from the cathodes on to a collector arranged at a negative potential to extract positive ions from the discharge as shown in Fig. 6(*c*). The upper collector is made in the form of a chevron baffle to permit gas to enter the pump. Unfortunately no data is available on the pumping speed of this design.

Penning type pumps will commence pumping in the glow discharge region (approximately 0·1 mm of mercury) providing sputtering occurs as discussed in Section 2 under ionization pumping. Hall obtained an ultimate pressure of 2×10^{-10} mm of mercury with a Penning titanium pump after it had been thoroughly degassed.

It is claimed that an advantage of the Penning ionization pump is that the metal deposition rate is self compensating, i.e. the rate of sputtering decreases with the fall in the positive ion bombardment which is proportional to the gas pressure. However, the pumping speed at a given pressure is less than that of a diffusion pump of comparable size. Certainly, of the getter-ion pumps described here, the Penning type will give least trouble in service because it has neither rotary members, which must operate without lubricants at low pressures, or a hot cathode that may burn out. Also, the ionizing efficiency of the Penning discharge is greater than that of the simple triode systems.

(d) *Barium getter-ion pump*

Cloud, Beckman and Trump(60) have made a getter-ion pump in which some 120 g of barium was evaporated inside a stainless steel container as shown in Fig. 7. They found that the pumping speed of a barium pump for oxygen and nitrogen, was increased by the ionizing discharge of a large Penning gauge mounted inside the gettering chamber. The speeds measured for nitrogen, with and without a Penning gauge in operation, are shown in Fig. 8(*a*), and those for oxygen and hydrogen in Fig. 8(*b*). The clean-up rate for hydrogen remained unchanged when the Penning discharge was operated, whereas the sorption rate for oxygen was doubled as shown in Table 2; the latter observation conflicts with those reported in Section 2(*c*). Cloud, Beckman and Trump found that the pumping speed (l./s) of their barium pump was independent of pressure and decreased with the mass of gas absorbed as shown in Fig. 8. The ultimate pressure of the pump was 10^{-7} mm of mercury. No attempt was made to raise the temperature of the getter to obtain a high clean-up rate as would appear desirable from Table 2.

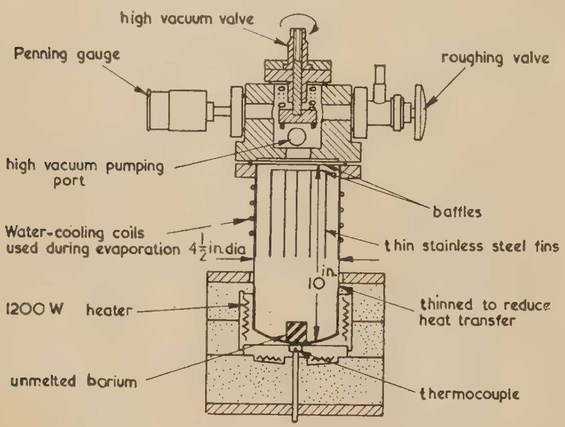


Fig. 7. Barium pump (after Cloud, Beckman and Trump(60))

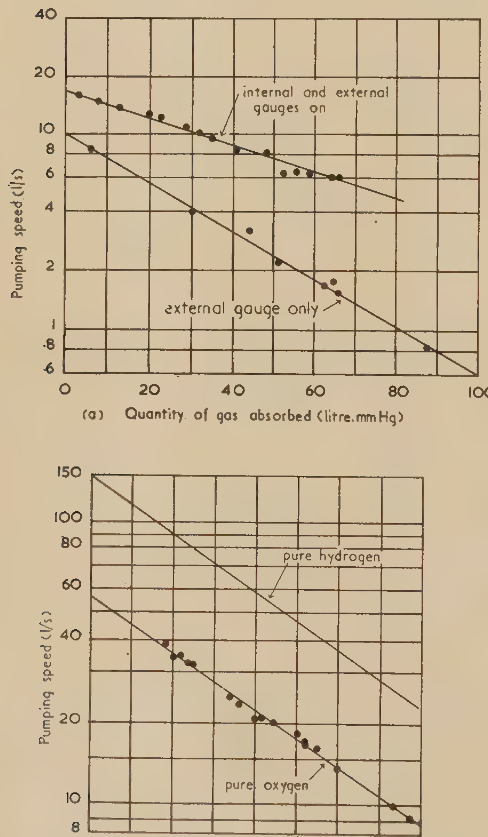


Fig. 8. Pumping speed of barium pump (after Cloud, Beckman and Trump(60))

(*a*) pumping speed for tank nitrogen; (*b*) pumping speed for pure oxygen and hydrogen.

5. FUTURE OF GETTER-ION PUMPS

Examination of the data given in Table 2 shows that, wh considered in terms of their dimensions, none of the gett ion pumps so far designed have the high pumping speed vapour stream pumps. The pumping speed of a diffus pump remains constant with time and does not vary mu with different gases. Ultimate pressures of the order 10^{-10} mm of mercury have been obtained with getter-i pumps after thorough baking, but those with a large throu put have not obtained better than 10^{-7} mm of mercury. fractionating oil diffusion pump charged with Apiezon C c be made to give a blanked off pressure of 5×10^{-8} mm mercury without the use of a cold trap, and failure to att such low pressures in kinetic systems usually arises from t use of volatile materials in their construction. A getter-i pump is normally used on a vacuum system which has be carefully designed to have a low degassing rate, e.g. me gaskets in place of rubber. If such methods are used with fractionating diffusion pump then a low ultimate pressu can be obtained with the added advantage of a high g throughput during exhaustion or when gas is admitted to t system.

Getter-ion pumps have certain operational advantag Thus oil vapour is not present which might back-stream in the exhausted vessel, and elaborate safety devices are n required to protect the equipment against failure of ref gerants or cooling water. A high vacuum isolation valve essential with a barium pump to prevent the metal oxi from flaking and entering the vacuum system when open to atmosphere. An isolation valve is also required with t large titanium pumps to permit periodic maintena Small getter-ion pumps may be connected directly to t exhausted vessel and have many advantages when used wi X-ray tubes, magnetrons, etc., which are carefully construct to have a low degassing rate.

One may produce ultra-high vacuum without the possibil of oil contamination from the vacuum pumps by reduci the pressure in a chamber from atmosphere to 1 μ of mercu with a helium cold finger and then completing the exhausti with a getter-ion pump.(61) Such a procedure may pro useful in research but is unlikely to be commercially applie

One of the most ambitious applications of getter-io pumps is that by Gould(63) of the Brookhaven Nation Laboratory who has fitted fifty titanium Evapor-ion pump in place of diffusion pumps on a half-mile long protc synchrotron. It has also been reported that the Russia thermonuclear machine "Ogra" uses a titanium getter pum in combination with mercury diffusion pumps. Informatic is not yet available on the effectiveness of either pumpin system, but the Russian method of boosting the performanc of conventional pumps by gettering would seem to be th more reliable.

It is evident from the foregoing analysis that getter-io pumps are unlikely to be used extensively where a high g throughput must be sustained, but their application can t expected to grow in research and in the electronic industry.

ACKNOWLEDGEMENTS

My thanks are due to Mrs. S. Holden for her assistance i the arranging of Table 1.

APPENDIX

When determining the performance of getter materia one may measure a number of different sorption propertie as discussed below.

Volumetric speed. It is shown in textbooks on the kinetic ory of gases that the number of molecules N striking unit a in unit time is $\frac{1}{4} n c$, where n is the number of molecules unit volume and c their average velocity. From this the ume of gas (N/n) arriving at unit surface in unit time at a en temperature can be found. If all of the gas molecules adsorbed on first impact then the pumping speed S of adsorbent for different gases would be as follows:

Gas	*air*	*oxygen*	*hydrogen*	*nitrogen*	*carbon dioxide*
. s^{-1} cm^{-2})	11·6	10	44	11·8	9·4

In practice, ideal speeds are not attained even for fresh faces and the measured speed S_m is equal to $a S$, where a an adsorption coefficient.

Wagener(36) has claimed for barium that the sorption rate) of a getter decreases with the mass of gas sorbed, but es not vary with the pressure P above the getter surface. lla Porta(37) has contested this and drawn attention to aknesses in Wagener's experimental method. He found barium that the sorption rate S_m measured at commence- nt of gettering was lower at high pressures, whereas the tial value of the mass sorption rate was increased. The ption rates of getters have been expressed in terms of S_m d S_mP by different workers and both conventions have d to be used in Table 1, because either S_m or P has not been orted.

A simple approach to this problem suggests that at any en stage in the sorption process, determined by the amount gas previously sorbed, there is a maximum rate at which the tter can sorb incident molecules. This would correspond a mass sorption rate such that $S_mP = kFM$, where F is number of gas atoms or molecules which can be sorbed r second and M their mass, and k is a proportionality ctor. If one measures S_m and S_mP at constant values of and as a function of the total gas sorbed, then the effect the simple relation given above would be as follows. hen P is above a critical value P_c then S_m would decrease cause the maximum rate of arrival of gas molecules would ceed the mass sorption rate (FM) of the getter. When $< P_c$ then S_m would remain constant because the rate ntrolling process would be the rate of arrival of gas mole- les at the getter surface. As the sorption proceeds FM uld fall so that P_c would decrease below P, thereby causing to fall. Examination of the results of Della Porta shows at they are in general agreement with this simplified eatment.

Sorptive capacity. The total amount of gas cleaned up by getter depends on the nature of the sorption mechanism. dsorption processes depend on the surface area of the posit and the total gas cleaned up may be expressed as a ass per unit area (l.μ/cm^2), where the surface area is the parent plane area of the film. A chemical reaction between getter material and sorbed gas gives the highest sorptive pacity and may be expressed as the mass of gas per unit ass of getter (l.μ/mg). It is usually necessary to heat a tter to accelerate the rate at which the chemical reaction curs and aid diffusion of the reactants through a surface in. One may compare the measured capacities for high mperatures working given in Table 1 with the values lculated by Dushman,(62) assuming the formation of oichiometric compounds. This shows that almost aximum sorption capacity for oxygen, nitrogen and drogen has been obtained with barium raised to approxi- ately 400° C.

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ORIGINAL CONTRIBUTIONS

High-temperature X-ray diffractometer

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A vacuum furnace designed for use with a commercial diffractometer is described. It uses a high-current heater made from tantalum foil, and allows the full Bragg spectrum to be recorded whilst satisfying the Bragg–Brentano focusing condition. The specimen temperature is uniform and can be measured accurately; the furnace has been operated successfully at temperatures up to 1100° C, and it is believed that considerably higher temperatures can be achieved.

High-temperature diffractometers have applications to many problems which are not easily tackled by conventional high-temperature Debye–Scherrer techniques; these include the plotting of isothermal transformation curves, the determination of Debye characteristic temperatures by the X-ray method, and the annealing of lattice defects. Various workers have described diffractometer furnaces,$^{(1-6)}$ but most of these have severe limitations in use. Only two permit examination of the whole Bragg spectrum, and one of these has no provision for heating in a vacuum. In this paper details are given of a furnace which has been used successfully in this laboratory over a period of two years; it is a modification of the Norelco diffractometer, a substantially identical version of which is now available commercially in Europe.

The apparatus was designed to satisfy the following conditions:

(i) attainment of a steady high temperature, uniform in the irradiated part of the specimen, and capable of being measured accurately;
(ii) easy temperature control, and facility for heating and cooling rapidly if desired;
(iii) specimen to be contained in a high vacuum chamber;
(iv) fulfilment of the X-ray focusing optics, easy alinement and secure mounting of the specimen;
(v) easy manipulation and interchange of all parts, including the specimen.

In external appearance, the apparatus resembles that designed by Chiotti$^{(5)}$ and the authors have followed Chiotti in using a high-current heater. The apparatus differs from his i several ways, notably the vacuum system, specimen mountin temperature measurement and furnace design.

BACK PLATE AND OUTER CAN ASSEMBLIES

The whole furnace assembly is carried on a hollow stainles steel shaft which replaces the specimen spindle of the gonic meter and also acts as a vacuum lead. The back plat (Fig. 1) is a recessed aluminium alloy disk with five "islands where the disk was not machined away; an outer brass plat is screwed securely to the aluminium plate so that th recessed portions form a water jacket, sealed by a rubbe gasket covered with sealing compound placed between thes plates. The central island is drilled and tapped to take th threaded end of the stainless steel shaft, which also has brass shoulder with a recess for an O-ring brazed to it. Th shaft is screwed in firmly to give a vacuum seal, and locke by a steel nut. Two of the other islands are also drilled t take the copper electrodes through which current is led t the furnace. Each electrode is cooled by a water gun an insulated by a Paxolin washer; the inside of the electrode i threaded, so that a nut and Paxolin washer may hold it firm The shoulders of the electrodes have grooves for the O-ring which make the vacuum seals, and the inside tips are tappe so that the heating assembly may be screwed into them.

The vacuum seal between the outer can and the back plat is made by a 6 in. radius O-ring, and three screws are house in the back plate for fixing the two assemblies together. Th outer can is also made from alumium alloy. A $\frac{3}{8}$ in. slot i t through 180° of the solid inner part for the X-ray inlet d outlet window, and a carefully machined casting fits osely over the inner part to which it is bonded to provide water jacket. Extra water cooling is provided by a copper be fitted in a recess in the block next to the window. The ermocouple tube (or optical pyrometer window) is mounted the centre of the can by an O-ring arrangement which is ear from Fig. 1.

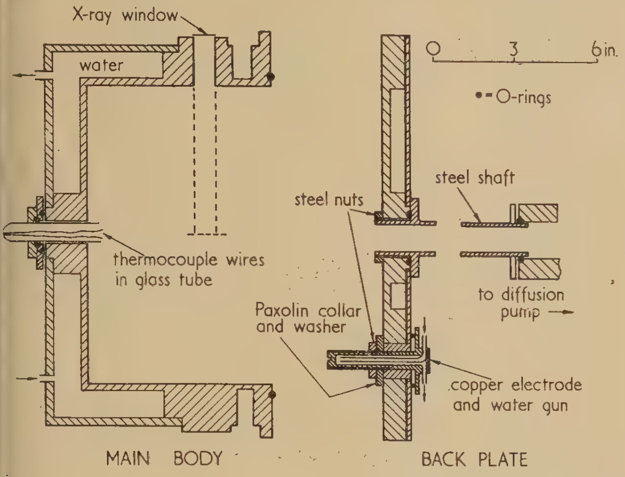

Fig. 1. Section through outer can and back plate of vacuum furnace

The window material and method of fixing presented some fficulty. In the early experiments, a thin aluminium foil as used, but this ruptured or developed pinholes very pidly. Later an aluminium —4% silicon foil, as developed the Fulmer Research Institute,(7) was found to be much ore satisfactory, although pinholes still tended to develop the higher temperatures. This foil was bonded to the lished rim of the aluminium can with Araldite No. 1, eformed into an anticlastic shape, and then cured at 70° r three hours. One window of this foil, 0·002 in. thick, sted for six months continuous use. Finally, the authors ere fortunate to be supplied with a window of 0·02 in. eryllium foil, which, in addition to being strong and free om pinholes, has much better X-ray transmission; the indow of this material has given no trouble since it was st installed.

The steel shaft is connected to the goniometer drive by a amping device identical to that used on the original instrument. In order to avoid damaging the driving gears and earings of the instrument, it is essential that the apparatus as light as possible; for this reason, the main construction in aluminium alloy, and all unnecessary metal is machined vay. The free end of the steel shaft is connected to the cuum line by means of an O-ring seal which allows tation of the shaft.

PECIMEN MOUNTING AND HEATER ARRANGEMENT

The method of mounting the specimen is shown in Fig. 2. he copper brackets are screwed to the two remaining islands the back plate. These brackets are slotted in the short ms taking the screws to the back plate, so that they may moved in a vertical direction only. The long arms are pped, and carry two 9 BA screws in each arm. These rews just fit into the bores of two pure alumina rods which rry the specimen holder, and one of which carries alumina eath spacers to hold the specimen and the end radiation shields in position. Thus the specimen is effectively thermally insulated, except for the thermocouple, which has a low thermal capacity relative to the large steel block of the holder. The specimen itself is contained in a recess in the holder, and can be either a carefully mounted solid block with a flat face, or (more usually) a powder. Occasionally, as in work on titanium, it is necessary to machine a complete solid specimen to the shape of the holder, and mount it direct on the alumina rails. It is essential that the brackets each have an angle of exactly 90°, and it is then possible to aline the specimen surface exactly on the axis of rotation of the goniometer. With the outer can removed, the whole instrument can be alined correctly with respect to the X-ray tube and Soller slit system by using the procedure specified for the commercial instrument.

The platinum/platinum–rhodium thermocouple fits into a hole carefully drilled in the specimen holder, such that the tip of the couple is approximately 0·001 in. from the recess in the holder. The alloy wire is insulated by pieces of thin alumina tubing. Both wires pass into a hole cut in the side of the alumina tube without spacers, and out through a similar hole outside the end radiation shields. The wires are sealed through a Pyrex glass tube, which is located in the hole in the outer can by an O-ring seal. Only one end radiation shield is shown in Fig. 2 for simplicity; usually three are mounted at each end, two between spacers, and a larger one next to the copper arms.

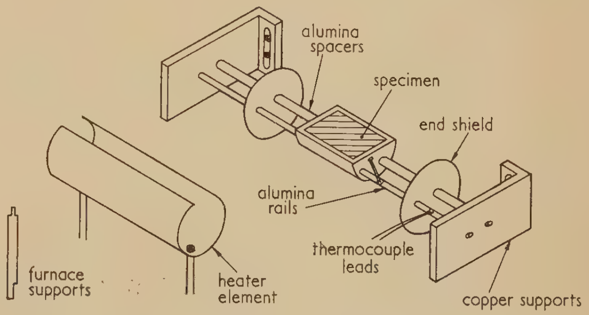

Fig. 2. Details of furnace and specimen mounting

The heater element is a cylinder of 0·002 in. thick tantalum foil, with a $\frac{3}{8}$ in. slot cut along the top to allow the X-rays in and out. This is screwed on to two $\frac{1}{4}$ in. diameter tantalum rods, threaded at the thinned tips to take tantalum nuts. The other ends of the rods have flat shoulders on them to bed against the copper electrodes, and are arranged to screw tightly against the electrodes, thus ensuring rigidity of the heater element and good electrical contact. The tiny holes in the heater which take the threaded tantalum supports are so positioned that the local hot spots produced there will tend to reduce the temperature gradient along the heater tube. Two concentric radiation shields of 0·004 in. thick tantalum foil have tabs which fit in slots in the copper brackets, with about $\frac{1}{16}$ in. clearance from the heater. These, and the end radiation shields, are dimpled to keep them apart from each other. Two additional flat radiation shields fit over the tip of the stainless steel shaft and into slots in the copper arms.

The power supply to the furnace is taken from a transformer giving up to 250 A at 4 V, the input being controlled by a 270 V Variac, fitted with a worm reduction to allow small changes to be made. The current is led to the electrodes through heavy flexible copper braid.

PERFORMANCE

The high-current heater is reasonably efficient, permits rapid heating and cooling and minimizes degassing difficulties. The specimen temperature, as measured by the thermocouple, can readily be controlled by hand to ±2° C. The highest temperature obtained is about 1100° C, but this represents only the limit of power available from the present transformer. It is hoped that higher temperatures may be achieved with a higher voltage transformer, although it may be necessary to provide an inner beryllium shield for the window, which reached about 70° C at the highest temperatures.

The vacuum in normal operation can be kept between 0·005 and 0·01 μ, and successful photographs of titanium have been taken up to 1100° C. After degassing, the specimen can be heated to 1000° C in about three minutes if required, and cooled to approximately 500° C in the same time. The accuracy of temperature measurement and uniformity of temperature have been checked by using the known lattice spacing temperature relations of silver. Lattice spacings were obtained from the positions of the high angle peaks by standard extrapolation methods; all the lines were sharp at all temperatures, suggesting the absence of appreciable temperature gradients. Re-measurement at room temperature after the high temperature runs proved the absence of contamination. The results are given in the table, together with the comparable measurements of Reynolds and Hum Rothery,(8) and both sets of results are plotted in Fig. It will be seen that the agreement is very good, showi that the temperature read from the thermocouple is ve close to the true specimen temperature.

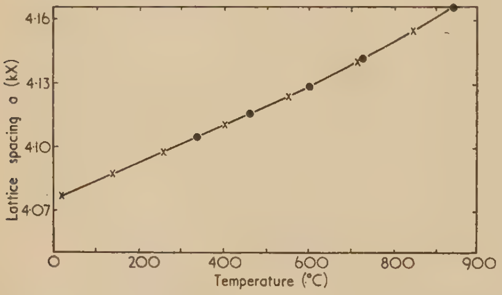

Fig. 3. Lattice spacing *versus* temperature curve for silver

× = present work.
● = Hume-Rothery and Reynolds.

Temperature (°C)	Lattice parameter in kX units Present work	 Hume-Rothery and Reyno
16	4·0773	
19·6		4·0775
22	4·0777	
134	4·0879	
257	4·0984	
337·5		4·1040
399	4·1102	
459		4·1149
552	4·1230	
596		4·1278
717	4·1395	
724		4·1407
846	4·1541	4·1542
943		4·1656

ACKNOWLEDGEMENTS

We should like to thank Dr. G. I. Williams for supplyi us with the aluminium–silicon foil, and for advice on preforming of this foil, and Prof. W. Hume-Rothery for interest in the work.

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Acoustic gas analyser

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An instrument capable of measuring the concentration of halothane (bromochlorotrifluoroethane) or chloroform vapour over a range of 0–4% by volume, with an accuracy of ±¼%, is described. The gas containing the vapour is a mixture of air and oxygen, and the instrument compares the time taken by a pulse of sound to travel through the original gas sample with the time taken for another pulse to travel through the same sample after the removal of the vapour by activated charcoal. Transistors are used throughout, and the instrument is small and self-contained.

The idea of inferring the composition of a gas mixture by making measurements of the velocity of sound is an old one, and many systems have been proposed.(1–9) These systems have used most of the methods of making sound velocity measurements with the exception of the oldest and, in principle, simplest method of all, that of measuring the time that an impulse takes to travel a certain distance. This is basically a very suitable method for gas analysis, and an arrangement for overcoming the practical difficulties of particular problem is presented below.

THE PROBLEM

In the course of an investigation into the properties o anaesthetic vapours, there arose a need for an instrumen that would conveniently and quickly determine the vapou concentration in the gas drawn from an anaesthetic circuit the measurements were to be made in the congestion of operating theatre, the instrument had to be small and f-contained.

The vapour is contained in a vehicle gas which may consist air and oxygen in any proportion. The velocity of sound anges with the composition of the vehicle gas by an amount ich cannot be ignored with respect to the changes due to presence of the vapour. To separate the changes in ocity due to variation in the composition of the vehicle s from changes due to the presence of the anaesthetic pour, the transit time of a pulse in the original sample is mpared with the transit time in the same sample after the noval of the vapour by activated charcoal.

THE GAS-HANDLING SYSTEM

Gas is drawn into a 50 ml. syringe and then expelled into acoustic tubes and absorbers (Fig. 1). The acoustic tube own immediately after the syringe is the sample tube, and transit time of a pulse through it is compared with the ansit time through either of the reference tubes. Each ference tube is preceded by a chamber containing activated arcoal. Until it becomes exhausted, the charcoal in the rst absorber chamber will completely remove the vapour om successive gas samples. Some vapour will then pass to the first reference tube and will be removed by the arcoal in the second absorber, so that the transit time of e pulses in the reference tubes will be different, and the ame meter readings will not be obtained in both positions f switch 1 (Fig. 3). This is an indication that the charcoal ould be changed. The volume of the gas system is small, nd three strokes of the syringe (150 ml.) will completely hange the gas in the system.

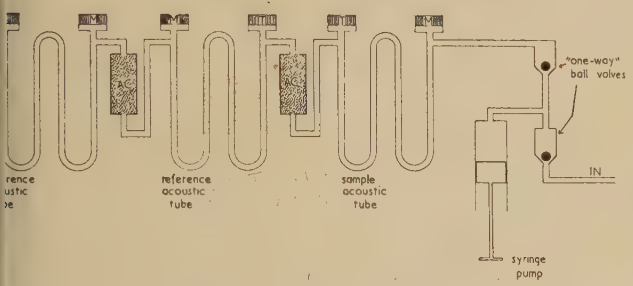

Fig. 1. The gas circuit

AC, activated charcoal; *M*, microphone; *T*, transmitter.

The acoustic tubes and transducers. Each acoustic tube is ade from a 1 m length of 2 mm bore Pyrex glass capillary be, bent to form a grid of six straight limbs connected by ends of 1 cm radius. The transducers (magnetic ear piece, pe 5A736 by Amplivox Ltd.) are cemented to brass collars hich are in turn cemented to the glass tubes. Gas passes to and out from the acoustic tubes through 1 mm bore opper tubes soldered into the collars.

THE ELECTRICAL CIRCUIT

Fig. 2 shows a block diagram of the circuit, together with ormalized drawings of oscilloscope traces at important parts f the circuit. The "sound-pulse generator," an asym- etrical multivibrator, produces about seventy electrical ulses per second which are converted into sound pulses by e transducers. The output from the receiver transducers amplified, limited and differentiated to produce uniform trigger pulses. In the channel associated with the sample tube (lower channel in Fig. 2), the trigger pulses initiate rectangular pulses in the "form pulse" stage, the duration of which are determined by the circuit constants in that channel. The trailing edge of these pulses is differentiated and used to terminate the rectangular pulses in the other channel. The circuit constants in this other channel are such that its rectangular pulses, if not terminated in this way, would be longer than those in the sample channel. Hence, the rectangular pulses in each channel begin at a time determined by the arrival of the acoustic pulses in the appropriate tube, but finish virtually at the same time. As the rectangular pulses of the two channels are of opposite polarity, a train of pulses, the width of which is proportional to the difference between the transit time of a pulse in a reference tube and the transit time of a pulse in the sample tube, and the polarity of which changes with the sense of the time difference, may be obtained by subtraction. The average current of the resultant pulse train is also proportional to the difference in transit times, and, after amplification, is used to operate a robust microammeter.

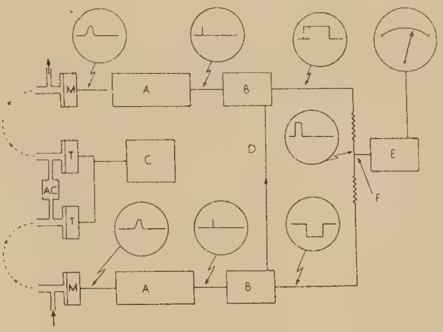

Fig. 2. Block diagram of gas analyser

A, amplify and limit; *AC*, activated charcoal; *B*, form pulse; *C*, sound-pulse generator; *D*, trailing edge signal; *E*, average and amplify; *F*, subtract; *M*, microphone; *T*, transmitter.

THE EFFECT OF TEMPERATURE

The circuit has been shown to work in ambient temperatures between 12 and 28° C, though there are changes in the meter reading corresponding to equal pulse transit times in the reference and sample tubes and changes in the deflexion from zero produced by a given difference in transit times. The change in sensitivity is about three parts in one hundred per degree centrigrade change of ambient temperature, the sensitivity increasing with an increase in temperature. The shift of zero is about four parts in one hundred of full-scale deflexion per degree centigrade change of ambient temperature. In practice, the instrument is checked for zero every half-hour, and for sensitivity every hour.

OPERATION

After flushing the acoustic tubes with room air the instrument is adjusted (RV_1, RV_3 depending on position of switch 1, Fig. 3) so that a meter reading of zero is obtained when the transit time of the pulse in either reference tube is compared with that in the sample tube. Then oxygen is introduced into the sample tube, leaving air in both reference tubes, and the sensitivity control (RV_3, Fig. 3) is adjusted so that a reading of thirty-three is obtained on the output meter. This calibration procedure gives a scale which is easy to

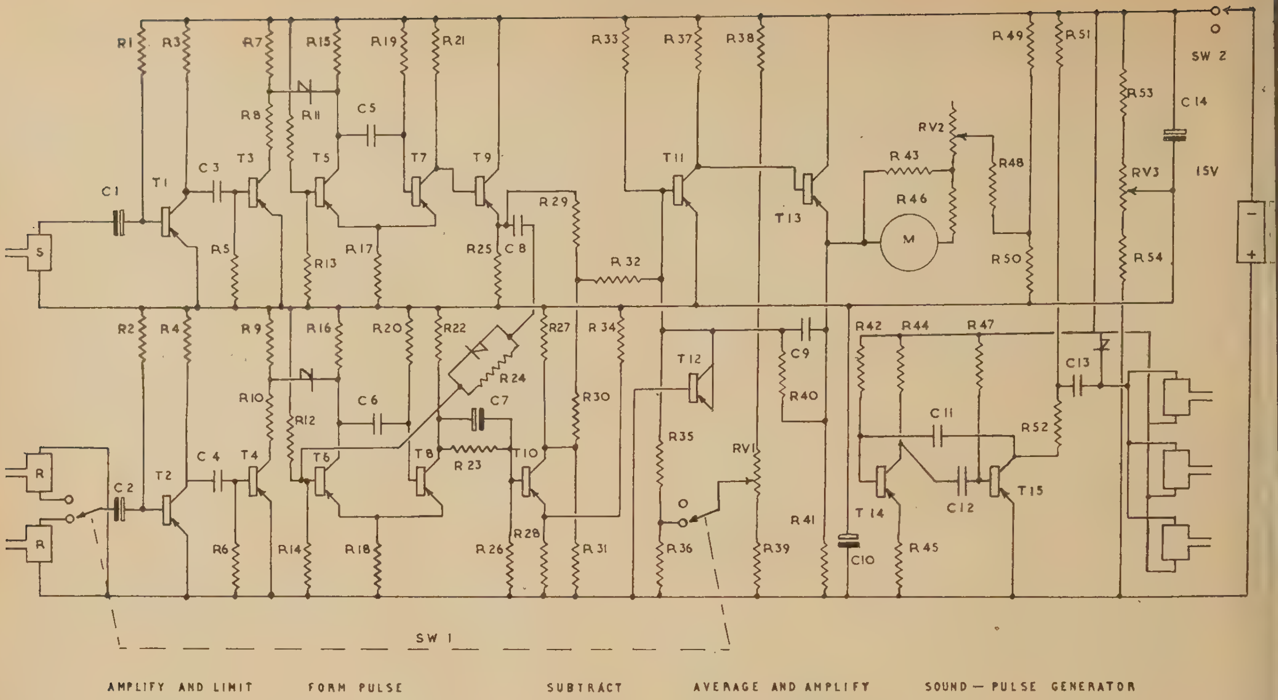
R1
R3
R7
R15
R19
R21
R33
R37
R38
R49
R51
SW 2
R8
R11
C5
R53
C14
RV2
C3
T3
T5
T7
T9
T11
R43
R48
RV3
15V
C1
T1
R29
R46
M
T13
S
R5
R17
R13
R25
C8
R 32
R50
R54
R2
R4
R9
R16
R20
R22
R27
R 34
R42
R44
R47
T12
C9
C13
R24
R10
C6
C7
R30
R40
R12
C11
R35
RV1
R52
C 4
T4
T6
T8
T10
R 23
T2
C2
R
R
T15
C12
R41
T 14
R28
R6
R14
R18
R 26
R 31
R 36
R39
C10
R 45
SW 1
AMPLIFY AND LIMIT
FORM PULSE
SUBTRACT
AVERAGE AND AMPLIFY
SOUND — PULSE GENERATOR

Fig. 3. Circuit diagram of gas analyser

R_1, R_2 = 270 kΩ
R_3, R_4 = 6·8 kΩ
R_5, R_6 = 220 kΩ
R_7 = 2·2 kΩ
R_8 = 6·8 kΩ
R_9 = 2·2 kΩ
R_{10} = 6·8 kΩ
R_{11}, R_{12} = 47 kΩ
R_{13}, R_{14} = 1 kΩ
R_{15}, R_{16} = 15 kΩ
R_{17}, R_{18} = 330 Ω
R_{19}, R_{20} = 180 kΩ
R_{21}, R_{22} = 6·8 kΩ
R_{23} = 22 kΩ
R_{24} = 680 kΩ
R_{25} = 6·8 kΩ
R_{26} = 2·2 kΩ
R_{27} = 6·8 kΩ
R_{28} = 100 Ω
R_{29}, R_{30} = 10 kΩ
R_{31} = 100 kΩ
R_{32} = 1 kΩ
R_{33} = 820 kΩ
R_{34} = 2·2 kΩ
R_{35} = 680 kΩ
R_{36} = 150 kΩ
R_{37} = 22 kΩ
R_{38} = 180 kΩ
R_{39} = 15 kΩ
R_{40} = 100 kΩ
R_{41} = 8·2 kΩ
R_{42} = 680 kΩ
R_{43} = 4·7 kΩ
R_{44} = 10 kΩ
R_{45} = 47 Ω
R_{46} = 2·2 kΩ
R_{47} = 470 kΩ
R_{48} = 3·3 kΩ
R_{49} = 2·2 kΩ
R_{50}, R_{51} = 1 kΩ
R_{52} = 330 Ω
R_{53} = 2·2 kΩ
RV_1 = 20 kΩ
RV_2 = 10 kΩ
RV_3 = 1 kΩ, 10-turn helical potentiometer

C_1, C_2 = 25 μF
C_3, C_4 = 0·1 μF
C_5 = 0·2 μF
C_6 = 0·35 μF
C_8 = 0·01 μF
C_9 = 0·5 μF
C_{10} = 25 μF
C_{11} = 0·6 μF
C_{12} = 0·01 μF
C_{13} = 0·25 μF
C_{14} = 25 μF

T_1–T_{10} = OC71, Mullard Ltd.
T_{11} = OC45, Mullard Ltd.
T_{12}–T_{14} = OC71, Mullard Ltd.
T_{15} = OC72, Mullard Ltd.

M = 100 μA meter

SW_1 = check/normal
SW_2 = on/off

S = receiver transducer in connexion with sample tube
R = receiver transducer in connexion with reference tube

All diodes are type OA71 by Mullard Ltd.
T_{11} and T_{12} are mounted in holes drilled in a 1 in. brass cube

interpret, as it has been shown by experiment that the concentration of either chloroform or halothane vapour may be taken (within the limits of accuracy required) as being directly proportional to the scale reading up to a concentration of 4%.

After the instrument has been set up in this way it is ready for use. Thereafter, an estimation of the concentration of anaesthetic vapour is made by operating the pump three times (150 ml.), checking that the same reading is obtained in both positions of switch 1 (Fig. 3), then dividing the scale reading by a factor appropriate to the anaesthetic in use. The factor is twenty for halothane vapour and ten for chloroform vapour. The number of estimations that may be made before the charcoal becomes exhausted is inversely proportional to the concentration of the vapour; at 2% at least fifteen estimations will be possible.

CONSTRUCTION

The component parts of the instrument, including the battery and a supply of charcoal, are contained within an aluminium case of overall dimensions 30 × 27 × 11 cm.

The absorber chambers, brass cylinders of bore 1·3 cm and 7 cm long, have a male Luer taper soldered to the lower end, while the upper is closed by a removable brass plug. Gas enters through the tapered joint and leaves through a gas port in the plug.

Power (12 mA at 15 V) is supplied by twelve mercury cell (type RMI by Mallory Ltd.), connected in series.

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lectrolytic hygrometers for measurements in gases down to a few parts per million

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Another method for making electrolytic hygrometers is described, together with detailed measurements of their characteristics. The hygrometer is well fitted for continuously recording the water content of suitable gases in ranges down to a few parts per million. An instrument is described for making rapid specification tests on cylinders of the refrigerant dichlorodifluoromethane.

INTRODUCTION

ere has long been a need to replace the usual gravimetric osphorus pentoxide absorption method for measuring all quantities of moisture in gaseous samples by one ich is more economical in time, manpower and material, d which is capable of giving a continuous record of the isture content of gas streams containing as little as a v parts per million (dew points about −70° C). These uirements can be met in favourable cases using the ctrolytic hygrometer first described by Taylor.(1) In that icle the method of construction and the evaluation of the sitive element were referred to only briefly. It is the ject of the present paper to describe a simpler method of nstruction and to discuss some measurements of the racteristics of the hygrometers in more detail. In addition rugged hygrometer is described for making rapid speci- ation tests on cylinders of Arcton 6 (dichlorodifluoro- thane).

GENERAL DESCRIPTION

In the electrolytic hygrometer the gaseous sample flows at teady rate (conveniently 100 ml/min) through a polytetra- oroethylene (PTFE) tube about 30 in. long and of 0·028 in. re. Inside the tube are two interlaced but separate helical ctrodes of fine platinum wire. The electrodes are covered h a thin film of partially hydrated phosphorus pentoxide d a voltage of about 70 V d.c. is maintained between them. e sensitive element (which is flexible) is coiled and potted Seekay wax (chloronaphthalene wax) in a ¾ in. bore ss tube 4 in. long (Fig. 1) provided with means for con- cting the gas supply and with terminals for the electrical cuit.

The principle of the method is that equilibrium is set up ten within a few minutes) between the rate of absorption water and the rate of electrolysis of the absorbed water. consequence the equilibrium current is proportional, by raday's law, to the rate of absorption of moisture. For a ; flowing at 100 ml/min at 20° C and 760 mm mercury, it readily shown that the equilibrium current is 13·4 μA per t per million by volume of water vapour. Since the uilibrium current I is proportional to both the water ntent W and the sample flow rate R, the water content in .m. v/v at 20° C and 760 mm mercury is given by

$$W = 100\, I/13{\cdot}4\, R \qquad (1)$$

ere I is in microamperes and R in millilitres per minute. some cases (for example, Arcton 6) the film does not sorb all the water from the sample; the water content can n be obtained by dividing 100 W by the absorption effi- ncy of the detector for the particular gas being used. A thod of determining the efficiency is described later.

Equation (1), which is applicable to any gas, is used throughout this paper. In the refrigeration industry, however, water contents are usually specified as a proportion by weight; the conversion factor for Arcton 6 is 1 p.p.m. w/w ≡ 6·7 p.p.m. v/v.

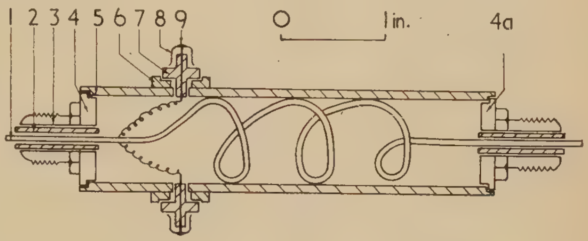


Fig. 1. Cross-section of detector

1, inlet end of sensitive element; 2, Fluon bush; 3, ¼ in. male flare union brazed to part No. 4; 4, 4*a*, brass end pieces; 5, brass tube filled with Seekay wax R93C; 6, boss brazed to brass tube; 7, Tufnol bush secured with Araldite; 8, metal cap secured with Araldite; 9, electrode soldered to metal cap.

Part No. 4 soft soldered to brass tube; part 4*a* attached with Wood's metal.

METHOD OF CONSTRUCTION

The following is a description of the methods of construction and sensitizing that have given satisfactory results; it should serve as an adequate guide to the manufacture of electrolytic hygrometers.

A mandrel consisting of about a metre of 22 s.w.g. Oxyferry wire is cleaned using hydrochloric acid. Two 40 s.w.g. platinum wires and two 40 s.w.g. copper spacing wires are close-wound helically on the mandrel in such a manner that adjacent turns of platinum wire are separated by copper. (A simple winding jig is readily made for this purpose.) After washing with trichloroethylene and acetone and drying, the assembly is lapped with unsintered PTFE tape ¼ in. wide and 0·007 in. thick using a two-thirds overlap. Flying leads are provided by folding back the platinum wires at one end of the winding and securing them with extra turns of tape. The PTFE tape is then sintered into a continuous tube by pulling the assembly at a steady rate of about 0·5 m/min through a tubular furnace about 1 m long at a temperature of about 400° C.

The PTFE tube is suitably constrained whilst the Oxyferry wire is stretched by about 25% and then withdrawn. The copper spacing wires are dissolved in weak nitric acid, and after washing with hot distilled water the tube is ready for potting. Details of the procedure are given in Appendix 1.

The detector is sensitized as follows. 50 ml each of distilled water, dioxan and acetone are pulled through the sensitive element in succession. After drying with nitrogen for a few minutes a resistance measurement is made to ensure that the insulation resistance between the electrodes is about 100 MΩ. 20 ml of a 20% solution of A.R. phosphoric acid in distilled water containing a wetting agent (0·1% Perminal BX) are then pulled through the detector and a voltage of 4 V d.c. is applied, the current being limited to 10 mA by a series resistor. Surplus phosphoric acid which bubbles out is absorbed with filter paper. After several hours the detector is purged continuously with a slow stream of dry nitrogen, any surplus phosphoric acid being removed as before. Once the detector begins to dry out the operating voltage is raised gradually to about 70 V. The drying characteristics of a good detector are described in Appendix 2. After drying the detector is ready for use.

CHARACTERISTICS OF DETECTORS

(*a*) *Absorption efficiency*. As stated earlier, in some cases the detector does not absorb all the water from a sample, and so it is necessary to determine the absorption efficiency for the particular gas being used. This can be done from measurements of the variation of the equilibrium current with sample flow-rate, using various samples each having a fixed water content within the range of interest; the water contents need not be known.

A convenient apparatus for doing this and which has been used in particular for conditioning Arcton 6 is depicted in Fig. 2. Arcton 6 vapour flows through a needle valve 1 past a mercury lute 2 into a flow-regulator 3 of the type described by Call.⁽²⁾ The vapour is then dried in the column 4 after which it passes through a sintered glass disk 5 in the bubbler tube 6 and into a spiral saturator 7 packed with glass beads. Both the bubbler and the saturator contain sulphuric acid of strength about 86% and are immersed in a bath of stirred water maintained at a constant temperature. The pressure of the Arcton 6 at the exit of the saturator is shown by a mercury manometer 8. The water content of the sample is controlled by controlling the temperature of the bath and the pressure of the vapour in the saturator.

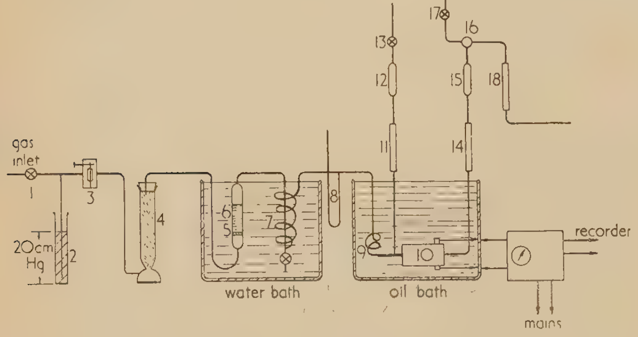


Fig. 2. Diagram of experimental arrangement

1, needle valve; 2, mercury lute; 3, flow regulator; 4, drying tower (P_2O_5); 5, sintered glass disk; 6, bubbler tube containing 86% H_2SO_4; 7, spiral saturator containing 86% H_2SO_4; 8, manometer; 9, spiral (stainless steel); 10, detector; 11, by-pass rotameter; 12, P_2O_5 guard tube; 13, needle valve; 14, detector rotameter; 15, P_2O_5 guard tube; 16, two-way valve; 17, needle valve; 18, nitrogen rotameter.

A short coil of 1/16 in. bore stainless steel tube 9 connects the conditioning system to the detector 10, both the coil and detector being immersed in stirred transformer oil at a controlled temperature. Just upstream of the detector a by-pass leads through a rotameter 11, a phosphorus pentoxide gua tube 12 and a needle valve 13 to waste. The rate of flow vapour through the detector is shown by the rotameter which is connected through a phosphorus pentoxide gua tube 15, a two-way valve 16 and a needle valve 17 to was When not in use the detector is kept dry by purging w Arcton 6; this is conveniently done by connecting a cylin through the rotameter 18 to the two-way valve 16 a purging backwards through the detector and to waste throu the valve 13, the detector current being left flowing. In t way the residual, or standing current in the detector c easily be kept below 10 μA. Current for the detector supplied from a mains unit provided with a microamme and with switched positions giving ranges (at a gas-flow ra of 100 ml/min) of 10, 50, 100 and 500 p.p.m. v/v. Provisi is made for connecting a 50 mV recorder giving the san ranges.

Using absolute gas pressures of (conveniently) 88 mercury and fixed saturator temperatures within the ra 15 to 35° C, observations are made of the equilibrium curre for flow-rates through the detector within the range 20 to 200 ml/min. Measurements are also made to ascerta that the saturator efficiency remains constant for flow-rat within this range; this is done by varying the saturator flo rate but keeping the detector flow-rate constant and as taining that the detector current also remains constant.

Four examples of typical curves obtained using Arcton and relating sample flow-rate and equilibrium current f different saturator temperatures are shown in Fig. 3. Fro

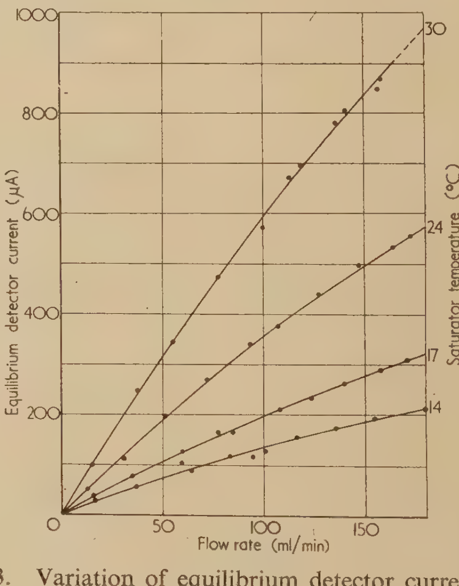
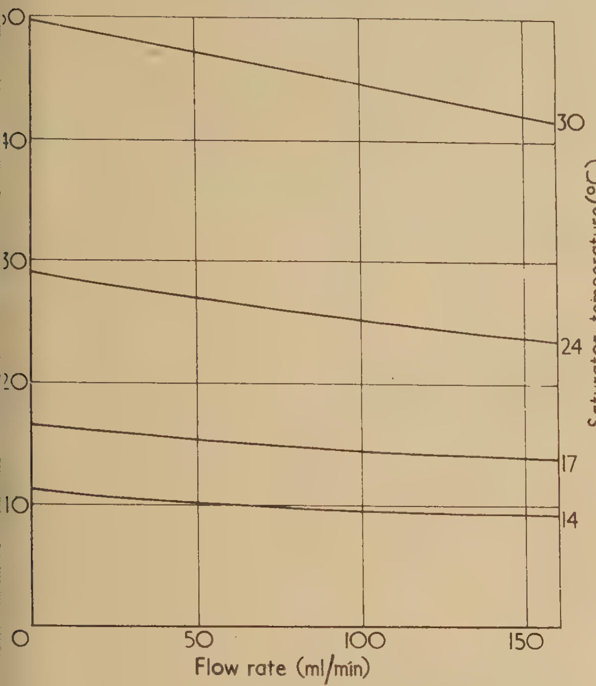


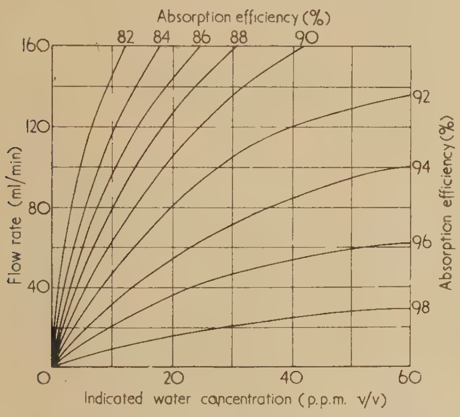
Fig. 3. Variation of equilibrium detector current with flow rate for Arcton 6

these curves can be derived, using equation (1), the curv depicted in Fig. 4, which show how the indicated wat content varies with sample flow-rate. By assuming that th intercepts obtained by extrapolating to zero flow-rate (infini contact time) represent the actual water contents, the absor tion efficiencies for various samples and flow-rates can obtained. The results are presented in Fig. 5, which sho the relation between indicated water content, sample flo rate and absorption efficiency for a detector with th dimensions described earlier. It can be seen that for th conditions usually met in practice, absorption is effective complete. The absorption efficiencies shown in Fig. 5 a ısiderably higher than those found for similar conditions Taylor.(1)

n the foregoing method it is necessary to subtract the nding current (3 μA in the present measurements) from measured currents, since otherwise the indicated water ıtent, calculated using equation (1), becomes infinite at o flow-rate (Taylor(1) does not mention this difficulty). is procedure is reasonable, since it is found that curves the type shown in Fig. 3 usually extrapolate smoothly to a ue which is the same as the standing current measured h dry gas purging backwards through the detector. rther, the standing current is found to be independent of rate of flow of dry gas, and consequently it is supposed t the electrolytic current is actually the measured current the standing current.



ig. 4. Variation of apparent water concentration with flow rate for Arcton 6, derived from Fig. 3



ig. 5. Relation between indicated water concentration, low rate and absorption efficiency of typical detector used with Arcton 6

b) *Temperature coefficient.* If the temperature of a ector in equilibrium with a moist gas stream is suddenly raised, the electrical conductivity of the film increases because of the positive temperature coefficient of conductivity for electrolytes. The increased current that will then flow tends to restore equilibrium by electrolyzing phosphoric acid at a greater rate until the conductivity and the current have fallen to their original values, by which time conditions should be as before except that the new equilibrium film will be drier than at the lower temperature.

In Fig. 6 are shown some measurements of the equilibrium current at different detector temperatures for eight samples of gas, the sample flow rates in each case being kept constant at values between 35 and 55 ml/min. These curves show that there is in fact a temperature coefficient, that between about 20 and 35° C it is much the same for all detector currents up to 200 mA, and further that it is not very different from that of the standing current, also shown in Fig. 6. These observations support the view that the electrolytic current is, as expected, independent of temperature, but that there is a small residual effect due to the temperature variation of the standing current. A useful working figure for the temperature coefficient over the range considered, obtained from Fig. 6, is 1·5 μA/°C, which for many practical purposes is negligible.

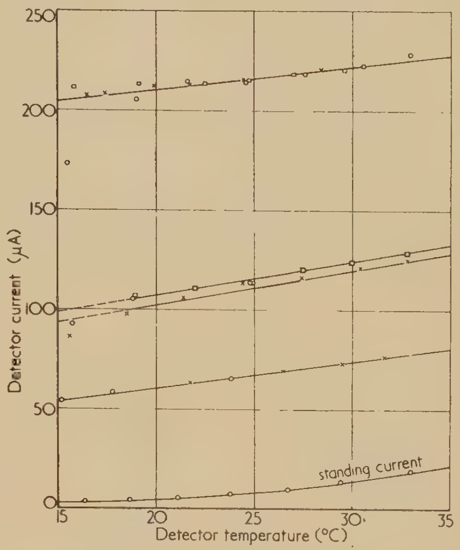


Fig. 6. Variation with temperature of equilibrium detector current at different water contents. Different symbols refer to different runs

(*c*) *Accuracy.* In Table 1 the expected water contents for the four sulphuric acid temperatures used in the measurements depicted in Fig. 3 and for acid strengths of 85·7% and 86·0% are compared with the water contents measured with the electrolytic hygrometer. The figure 85·7% was determined by titration, and the expected water contents were calculated for an Arcton 6 pressure of 88 cm mercury

Table 1. *Comparison between measured and calculated water contents*

Saturator temperature (°C)	*Water content (p.p.m. v/v)* Measured	*Expected* 85.7% *acid*	86.0% *acid*
14	11	13	11
17	17	18	16
24	29	32	29
30	50	53	48

using the results of Greenewalt[3] for the partial pressure of water vapour over aqueous sulphuric acid. It may be seen from Table 1 that the measured water contents are roughly 10% below those to be expected for an acid strength of 85·7%, but that they would be in good agreement if the acid strength were 86·0%.

Greenewalt correlated data from many sources and claims that his results for the partial pressure of water are accurate to within 2%. The discrepancies of about 10% can therefore reasonably be ascribed to the difficulty of determining the acid strength with the required accuracy.

In addition a direct comparison has been made between the electrolytic hygrometer and a gravimetric phosphorus pentoxide absorption apparatus of a type used for routine tests. The sample for the gravimetric apparatus was taken from the by-pass line of the hygrometer and after passing through the absorption tubes was condensed at −80° C before weighing. Samples of about 600 g each were collected in periods of about 2½ h, the temperature of the sulphuric acid bath being controlled at values corresponding to water contents of about 25, 40 and 85 p.p.m. v/v respectively. The results by the two methods for 12 samples are compared in Table 2; it can be seen that the agreement is satisfactory.

Table 2. *Comparison between electrolytic hygrometer and phosphorus pentoxide absorption method*

Electrolytic hygrometer (p.p.m. v/v)*	*P_2O_5 absorption method† (p.p.m. v/v)*
23	24
23	27
22	27
22	24
42	40
42	40
41	40
42	44
83	84
83	84
85	84
83	87

* Equilibrium times 5 to 10 min.
† Precision about 3 p.p.m. v/v.

It is clear from the figures in Table 2 that for 40 and 85 p.p.m. agreement between the two methods is within 5%. The discrepancy at about 25 p.p.m. could be due to the relatively large weighing error in the gravimetric method, where at this water content the mass increase of the absorption tubes is only about 2 mg. It seems not unreasonable to conclude from these and the foregoing measurements that the accuracy of the hygrometer is certainly within 10% in the range 10 to 100 p.p.m. v/v and that under suitable conditions the hygrometer is a convenient and absolute method for measuring very low concentrations of water in gases.

PROTOTYPE PLANT INSTRUMENT

From what has been said it is clear that the electrolytic hygrometer is well fitted for the continuous monitoring of gas streams. It has been found possible also to use a hygrometer for testing individual cylinders of refrigerants to specification in quick succession. A diagram of an instr ment of this type is shown in Fig. 7. Connection to the val of a cylinder of refrigerant is made by means of a pneuma clamp, which can be opened or closed by means of a tw position valve spring-loaded in such a way that the clar tends to close. To the clamp head is attached a short leng of stainless steel capillary, which in turn is connected throu a flexible length of $\frac{1}{8}$ in. bore coiled copper tubing to a lon taper vaporizing valve. The copper tube has a volume about 20 ml. The exit of the vaporizing valve is connect by a short length of $\frac{1}{4}$ in. outer diameter copper tubing a flare unions to a detector provided, as described earli with rotameters, phosphorus pentoxide guard tubes a needle valves. Current is supplied by the usual mains unit.

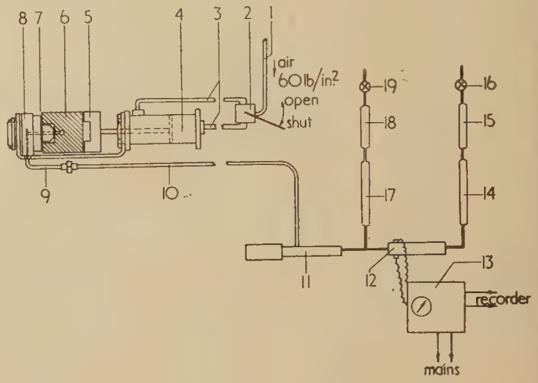


Fig. 7. Diagram showing pneumatic cylinder clamp, expansion valve and hygrometer for use on Arcton 6 plant

1, flexible air hose; 2, two-way air valve; 3, flexible hoses t air cylinder; 4, air cylinder; 5, piston end fitting; 6, valve body of Arcton 6 cylinder; 7, joint ring; 8, clamp head; 9, capillary take-off pipe; 10, $\frac{1}{8}$ in. bore copper feed-pipe (6 ft long); 11, adjustable vaporizing valve; 12, detector; 13, power unit incorporating range switch and meter graduated in p.p.m. v/v; 14, detector flow rotameter; 15, P_2O_5 guard tube; 16, needle valve; 17, by-pass rotameter; 18, P_2O_5 guard tube; 19, needle valve.

A measurement is made by first attaching the pneumat clamp to the valve of the sample cylinder, opening the val and flooding the copper tube with liquid refrigerant. T vaporizing valve and the two needle valves are then adjust so that the by-pass flow is conveniently about 50 ml/min an the detector flow is as nearly as possible 100 ml/min. T water content is then obtained directly from the record trace, or the meter, after equilibrium has been reached. T changeover to the next cylinder is done as follows. Aft shutting the cylinder valve the pneumatic clamp is opene removed from the cylinder, and then shut. During the tim the clamp is open most of the liquid refrigerant left in th copper tube vaporizes through the stainless steel capillary the clamp head. A small quantity of liquid remains, however, and the clamp is attached to the next cylinder after th liquid has vaporized from the copper tube but before th pressure of the residual vapour has fallen to atmospheri In this way it is found that although frosting occurs durin the vaporization, very little moisture enters the syste from the atmosphere during the changeover.

Hygrometers of this type are now in regular use for spec fication tests on cylinders of Arcton 6. It is found tha samples well below and well above specification can usual be accepted or rejected in two minutes; borderline case may need about twenty minutes. The volume of samp ed is less than one twentieth, and the time required is about e two-hundredth of that for the gravimetric method, and special skills are needed for making the tests.

If oil is present, even in trace quantities, it tends to accumu- e in the vaporizer and in the detector; the response time wly increases until eventually no response at all can be tained, and it is then necessary to clean the detector and renew the sensitive film. In the case of Arcton 6, oil ntamination has been prevented by fitting two Porosint tered-bronze filters, a coarse (grade *C*) one just down- eam of the vaporizer and a fine (grade *A*) one at the tector inlet.

When the detector is not in use, the standing current can sily be kept down to 10 μA by back-purging with Arcton 6 a rate of 2 ml/min, as described earlier.

OTHER APPLICATIONS

Although most of the work so far has been directed wards measuring the water content of Arcton 6, the elec- olytic hygrometer is by no means limited either to Arcton 6 to such low water contents. Currents as high as 75 mA ve been recorded with wet Arcton 6 flowing at rates up to 0 ml/min, with no deleterious effect on the sensitive ele- ent. This corresponds to a water content of about 00 p.p.m. v/v, and there seems no reason why even wetter s streams should not be measured simply by using smaller w rates. Measurements have also been made on nitrogen d on air.

CONCLUSIONS

It has been shown that electrolytic hygrometers can be bricated in the laboratory without great difficulty, and that ey can be used to measure the water content of Arcton 6, e accuracy in the range 10 to 100 p.p.m. v/v (1·5 to 5 p.p.m. w/w) being within 10%. The hygrometers are not mited to Arcton 6; measurements have been made with air d nitrogen and there is no reason to suppose that the ater content of any clean gas that does not react with hosphoric acid or platinum could not be measured. Experi- ents have shown that water contents as high as 7000 p.p.m. v can also be measured, and no doubt even wetter streams ould be monitored simply by using proportionally smaller ow-rates.

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APPENDIX 1

Potting the sensitive element

The following procedure has been found to give satisfactory results. After tinning the ends of the brass tube and the edges of the end-pieces (Fig. 1), the end-piece nearer the electrodes is soldered in place and the sensitive element inserted. The flying leads are threaded through the holes in the brass tube and in the Tufnol bushes and are then soldered to the metal caps. The bushes and caps are fixed in position with Araldite D, and the brass tube is filled with Seekay wax grade R93C (melting-point 90 to 95° C). The remaining end-piece can then be soldered in place with Wood's metal by using a thermal shunt and judiciously heating the end of the metal tube to about 75° C, without any further melting of the wax.

This procedure avoids any risk of weakening the Araldite joints which might otherwise arise when soldering the end-pieces in place. Leaky joints at the electrodes and at the edges of the end-pieces give rise to an unduly high standing current by allowing atmospheric moisture to diffuse into the system (against even an excess pressure).

APPENDIX 2

Drying characteristics of detectors

When a newly-coated detector begins to dry out it is often advantageous to incorporate it straight into the system in which it is to be used. Where practicable all exits should be provided with moisture traps and a slow stream of nitrogen or other suitable clean gas should be passed continuously through the detector via one of the moisture traps. Under these conditions it is found that with a good detector the current falls to about 25 μA by the third day. Thereafter, further slow drying takes place, the current falling in a typical case to 5 to 10 μA by the fourteenth day. Standing currents even smaller than this have been observed on prolonged drying even though daily measurements were being made in which currents of 1 mA were recorded. The lowest standing current yet achieved in a detector is 0·5 μA. This suggests that the limit of detection of the hygrometer has still to be reached.

One troublesome source of an unduly high standing current is the bubbling out of the phosphoric acid from the ends of the sensitive element during the initial drying of a detector. Phosphoric acid sometimes gets trapped in small quantities in the cavities where the sensitive element emerges from its housing, and it can easily prevent the standing current falling below 50 μA. This risk can be avoided by covering the ends of the sensitive element with filter paper during the initial stages of drying, and subsequently wiping the ends with damp filter paper.

Photographic method for pulse amplitude analysis

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[*Paper first received* 13 *August, and in final form* 7 *October*, 1958]

The problem of determining the magnitude distribution of fast rising voltage pulses is of frequent occurrence. A method is described by which such pulse height spectra may be obtained by photographing a cathode-ray oscilloscope display, in which the only tops of the pulses appear on the screen. The time base is switched off and the exposure is adjusted to permit the film to integrate the blackening due to a large number of individual pulse tops. The density variation on the film may be shown to be closely related to the pulse height spectrum and may be obtained from a densitometer measurement. Full details are given of the circuits used to obtain such a display, together with a summary of the applications to which the technique is particularly suited.

The authors have been concerned, for some time, with the determination of the magnitude distribution of ionization and scintillation pulses produced in solids subjected to α- and β-particle bombardment. The problem has been to obtain such spectra under widely different experimental conditions. The resolution needed was not high, but the fact that the ionization pulse spectra were not constant with time meant that a reliable spectrum was obtained only if a statistically large number of pulses was recorded *before* the time variation became appreciable. Single-channel pulse analysis was not suitable, since this technique did not permit the above condition to be fulfilled, and the achievement of even quite low resolution was laborious and time-consuming, especially when this method was used for a large number of spectra. It became obvious that a method permitting simultaneous recording of pulses of all magnitudes was desirable. An obvious choice was an electronic multi-channel pulse amplitude analyser but the cost of such an elaborate device did not seem to be justified by the degree of precision inherent in the experiments to be performed. The photographic method described below was adopted and proved to be extremely flexible in application. The authors' attention has since been drawn to descriptions of comparatively elaborate devices which involve similar principles,(1, 2, 3) but they consider that the simplicity of the present technique may commend it to workers in fields with similar requirements and that it is therefore worthy of separate record.

PRINCIPLES

If a pulse spectrum is presented on an oscilloscope with the time base switched off and the display is photographed on a stationary film for a fixed interval, then a vertical trace of varying density will appear on the film. The density of blackening along the trace will depend on the following factors.

(i) The pulse maxima, where the writing speed is low, will contribute strongly to the blackening in a way that is a function of the pulse spectrum.

(ii) The glow from the undeflected spot will cause a blackening on the film, which is a maximum at the point of zero pulse height and which decreases in an unknown way with distance from this point.

(iii) The tails of the pulses will produce a density distribution related to the pulse spectrum, but with a maximum at the zero position.

The resulting density distribution on the film is therefore related to the integral bias curve, but it is not susceptible of simple interpretation. If it is arranged that only the tops of the pulses contribute to the blackening, and that each pulse top produces a spot of light of an intensity which is independent of the pulse amplitude, and if the developed film density is a faithful reproduction of the light intensity incident upon it, then the density variation is closely related to the pulse height spectrum. These requirements may be fulfilled, in a simple manner, within the limits of accuracy desired in many pulse analysis experiments.

METHODS

The first method to be described was devised by one of the authors (P. J. K.) and has been extensively tested and used.(4) The second method incorporated improvements and additional facilities which this experience suggested.

If the brilliance of the cathode-ray oscilloscope is biased so that the trace appears only when a given pulse reaches its peak value, then factors (ii) and (iii) above no longer contribute, and only the desired distribution of pulse tops is presented to the film. To achieve this the method illustrated in Fig. 1 was adopted. The pulses to be analysed were taken to two linear amplifiers (type 1008) connected in parallel. Amplifier *A* was used with fast time constants so that its output pulse had a fast rising leading edge (about 1 μs). This pulse was fed to a discriminator unit which gave, for each input pulse above the variable threshold level, a fast negative-going square wave of constant amplitude and variable duration. This pulse was used to trigger the brilliance of the oscilloscope. Amplifier *B* was used with slower time constants and the resulting slowly rising pulse was presented on the cathode-ray oscilloscope. By suitable adjustment of the time constants of amplifier *B* and the duration of the square wave, it was arranged that the brilliance trigger pulse was synchronized with the maximum of the display pulse, so that the tops of the pulses appeared as small dots on the screen when no time base was used. The film was exposed to a large number of these pulses and the resulting film trace, when densitometered, gave a measure of the magnitude distribution of the pulses.

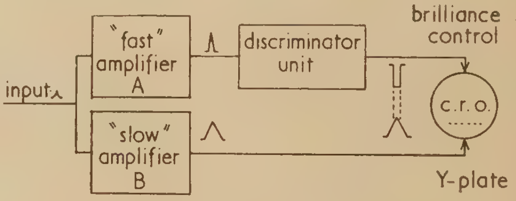

Fig. 1. Block diagram of first method

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Certain precautions are necessary to ensure that the stem gives a true representation of the pulse spectrum.

(i) To ensure that each pulse gives a dot of equal intensity ı the tube phosphor, no matter at what position along the ıce it appears, it is necessary to obtain a cathode-ray tube ıth a uniform phosphor and a constant brightness character-ic across the tube face, and to ensure that the magnitude the brightening pulse does not depend on the triggering ılse.

(iii) To avoid amplitude distortion in the pulse spectra the flexion sensitivity of the cathode-ray oscilloscope must be ıear over the area used.

(iii) Errors may be introduced in the photographic process ıless care is taken to work only within the proportional tensity region of the film characteristic, and a standard velopment process must be adhered to.

(iv) Care is necessary in the process of transfer of the nsity variations on the film to deflexions on a recorder. he densitometer used in the present work was designed by r. P. M. B. Walker of this Laboratory and the precautions commended in its use have been described by him.(5)

When these conditions had been fulfilled, extensive tests ere carried out with pulse spectra of known shapes. The sult of one such test, with a sine wave, modulated-pulse stem, is shown in Fig. 2 to illustrate the measure of agree-ıent obtained between the photographic technique and ngle-channel analysis of the same pulse system.

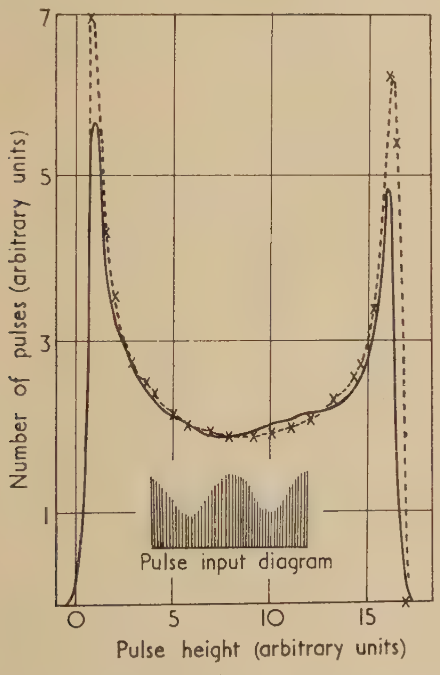

Fig. 2. Experimental test with sine wave, modulated-pulse system. Dotted curve obtained using a single-channel analyser. Full curve obtained using pulse-brightening technique

The results of these tests were encouraging and no serious imitation in the method was found. On the pulse height ıxis agreement was shown to be very close [Fig. 3(*a*)] and in ıractice this type of measurement is usually the more ımportant. On the pulse frequency axis agreement was ound to be within ±5% [Fig. 3(*b*)]. These observations ıpply to that part of the cathode-ray tube face normally used—i.e. a circle of diameter approximately three-quarters of that of the screen. The method did, however, suffer from two rather important drawbacks. It required the use of two expensive amplifiers and the shape of the displayed pulse was fixed by the requirements of the brightening technique. The second method, described below, was designed to eliminate these disadvantages and to increase the flexibility of the apparatus.

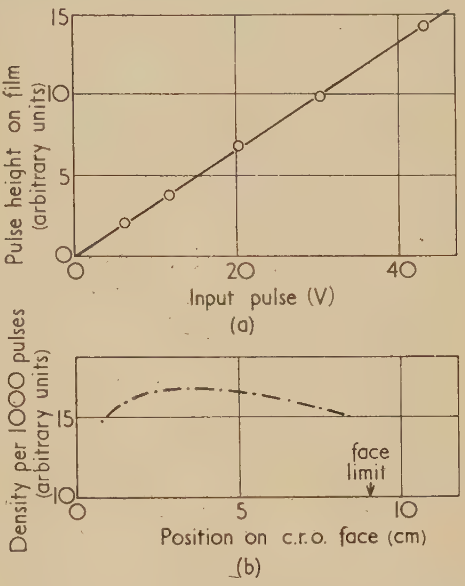

Fig. 3. Tests of pulse brightening technique

(*a*) "Height axis" linearity.
(*b*) "Number axis" linearity.

Fig. 4 illustrates the interconnexion and functions of the various circuits used in the second system. The part shown between *C* and *D* in Fig. 4, which is given in greater detail in Fig. 5, was constructed by the second author (P. J. D.). The remaining circuits were available in the commercial

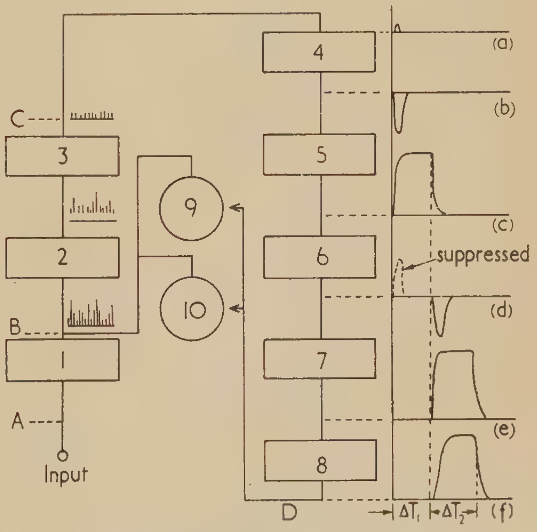

Fig. 4. Block diagram of trigger circuit

1, amplifier; 2, discriminator; 3, mono-stable multivibrator; 4, inverter amplifier; 5, mono-stable multivibrator; 6, differentiator suppressor; 7, mono-stable multivibrator; 8, cathode follower.

apparatus which was already in use. The pulses to be analysed were taken, after suitable linear amplification, from point *B* of Fig. 4 to the Y-amplifier of the Cossor type 1049 oscilloscope where the display was photographed. The pulses at point *B* were also presented to a variable discriminator, and those above the threshold level triggered a monostable multivibrator. The output of the multivibrator is shown at *C* in Fig. 4 and the voltage waveforms produced at various points of the circuit by each pulse at *C* are illustrated in the sequence of graphs. The pulse at *D* served to switch the electron beams of the oscilloscope and monitor on for an interval depending on the setting of ΔT_2, and delayed by time ΔT_1 after the leading edge of the displayed pulse; ΔT_2 was used at the minimum setting except when very long amplifier time constants were employed.

Use of the monitor unit enabled the pulse spectrum to be viewed during the photographing of the oscilloscope tube and all preliminary adjustments, which involved the use of high brilliance levels, were made with the aid of this tube to avoid fatigue effects in the phosphor on the camera tube. The large output from the brightening circuit at *D* (+80 V) made it possible to brighten only the maxima of the pulses over a wide range of settings of the oscilloscope brightness control. In practice this control was found to be a convenient way of varying the resolution of the system. Th exposure times were normally fixed by the time rate variation of the pulse system, and for low counting rates was sometimes expedient to sacrifice resolution to achie sufficient trace blackening in one exposure. With the bri liance control at the minimum setting, the effective numbe of separate channels on the densitometer record was measure for pulses much larger than the amplifier noise level an found to be about sixty. Synchronization of the brightenin interval with the peaks of the displayed pulses was foun always to be possible if the amplifier time constants were no less than 2 μs. This was satisfactory as it was generall desired to use the 8 μs setting, which gave maximum signa to-noise ratio for ionization pulses and most types of scinti lation pulse.

The circuit diagram of that part of the pulse brightenin system indicated between *C* and *D* in Fig. 4 is shown i Fig. 5. It was necessary to stabilize the h.t. supply voltage for reliable operation, and the h.t. negative line was ma adjustable to enable the desired operating condition to readily arranged. The actual values for anode-grid coupli components and the waveform speed controls RV_1 and RV_2 indicated in Fig. 5, were found by trial while the waveform were under measurement. Great care was taken in th

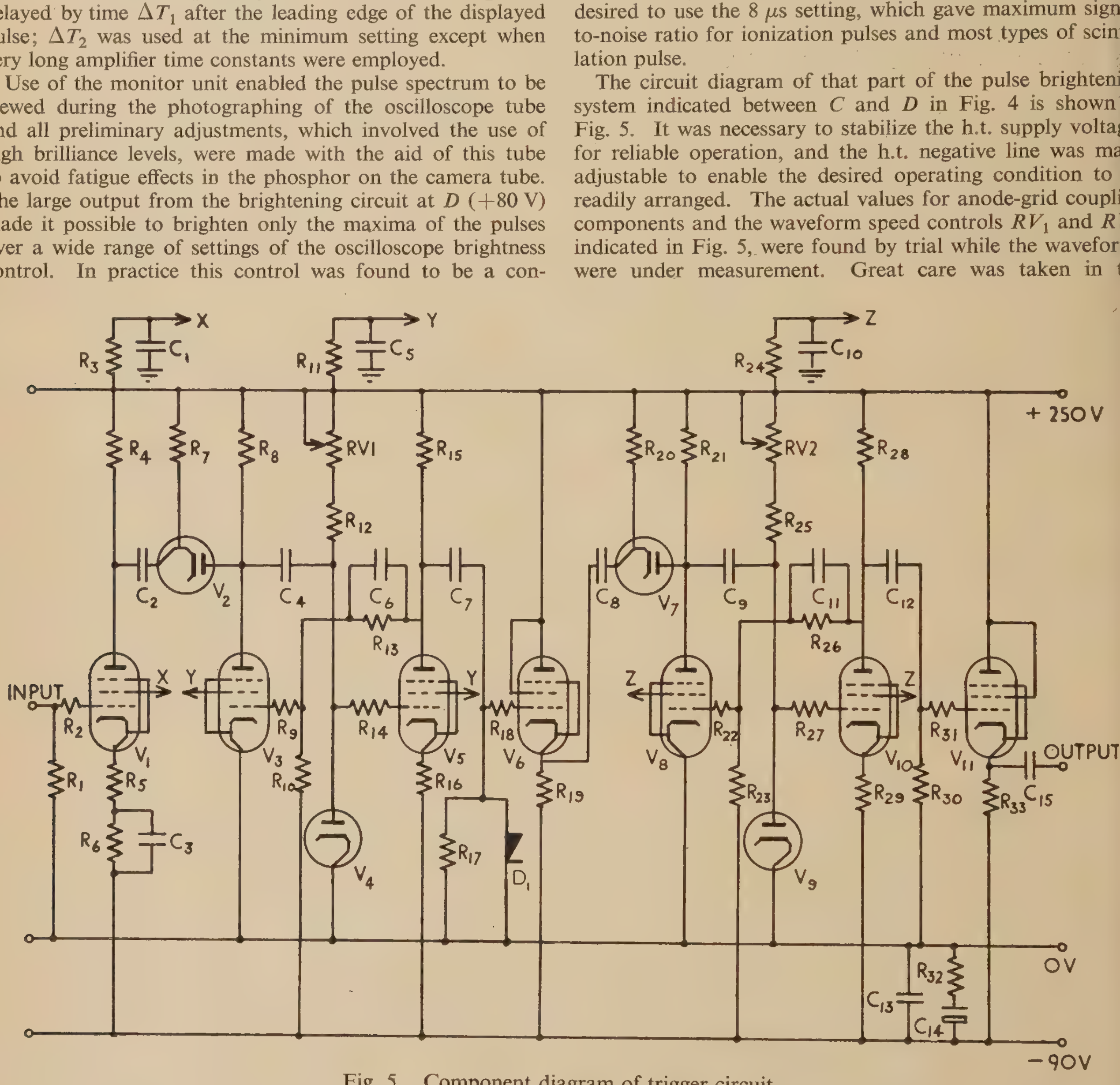

Fig. 5. Component diagram of trigger circuit

R_1 = 100 kΩ, ¼ W
R_2 = 100 Ω, ¼ W
R_3 = 50 kΩ, 1 W
R_4 = 10 kΩ, 2 W
R_5 = 1 kΩ, 2 W
R_6 = 10 kΩ, 2 W
R_7 = 100 kΩ, ½ W
R_8 = 10 kΩ, 2 W
R_9 = 100 Ω, ¼ W
R_{10} = 150 kΩ, ¼ W
R_{11} = 100 kΩ, ½ W

R_{12} = 50 kΩ, 1 W
R_{13} = 320 kΩ, ¼ W
R_{14} = 100 Ω, ¼ W
R_{15} = 12·2 kΩ, 2 W
R_{16} = 10 kΩ, 2 W
R_{17} = 220 kΩ, ¼ W
R_{18} = 100 Ω, ¼ W
R_{19} = 22 kΩ, 2 W
R_{20} = 100 kΩ, ¼ W
R_{21} = 10 kΩ, 2 W
R_{22} = 100 Ω, ¼ W

R_{23} = 175 kΩ, ¼ W
R_{24} = 100 kΩ, ¼ W
R_{25} = 50 kΩ, 1 W
R_{26} = 350 kΩ, ¼ W
R_{27} = 100 Ω, ¼ W
R_{28} = 15 kΩ, 2 W
R_{29} = 10 kΩ, 2 W
R_{30} = 2·2 MΩ, ¼ W
R_{31} = 100 Ω, ¼ W
R_{32} = 10 Ω, ¼ W
R_{33} = 22 kΩ, 1 W

RV_1 = 3 MΩ
RV_2 = 80 kΩ

C_1 = 0·1 μF
C_2 = 0·001 μF
C_3 = 0·1 μF
C_4 = 180 pF
C_5 = 0·1 μF
C_6 = 0·001 μF
C_7 = 10 pF

C_8 = 0·001 μF
C_9 = 300 pF
C_{10} = 0·1 μF
C_{11} = 27 pF
C_{12} = 270 pF
C_{13} = 0·01 μF
C_{14} = 24 μF
C_{15} = 0·001 μF

D_1 = GEX34

V_1 = EF91
V_2 = EB91
V_3 = EF91
V_4 = EB91
V_5 = EF91
V_6 = EF91
V_7 = EB91
V_8 = EF91
V_9 = EB91
V_{10}, V_{11} = EF91

ign of the component layout to reduce stray capacitance ll critical points such as the anodes of V_3, V_5, V_9 and V_{11}. The system was tested by measuring the scintillation ctra, generated in a crystal of Pamelon (by Isotopes velopments Ltd.), by α- and β-sources of radiation (^{210}Po 1 ^{90}Sr). Good agreement was obtained between the ctrum given by the pulse brightening technique and that ained with the aid of an electronic single-channel analyser.

APPLICATIONS

a) Both methods have proved adequate for pulse spectra ere the shape of the displayed pulse may be arbitrarily sen.

b) Unlike most methods of multi-channel analysis, a two- nensional display is possible with both of the methods cribed above. That is to say, the pulse used to trigger the ghtness is not necessarily generated by the pulse to be played. This enables the time relationship between two se systems to be obtained. In addition, if two pulse tems are presented separately on the *X*- and *Y*-plates of oscilloscope, the brightness trigger being generated by or other of them, then the display shows their relation- p in magnitude as well as in time (see Ref. 4).

c) When two pulse systems are used then, if the discrim- tor unit shown in Figs. 1 and 4 is replaced by a single- nnel analyser, the spectrum of one pulse system associated h a narrow range of pulse heights in the second (triggering) se system may be found.

d) If the connexion to the *Y*-plates of the oscilloscope is ken, then the pulses high enough to pass the discriminator threshold all produce dots on the same spot on the phosphor of the cathode-ray tube. If the film is driven at a slow speed and exposed to the cathode-ray tube, then the resulting horizontal blackened trace will give, when densitometered, the variation of counting rate with time. This method is particularly suited to situations where the counting rate is changing rapidly with time, and this is just the case when other methods of analysis often prove unreliable and difficult to use. The time axis can be calibrated accurately if a synchronous motor is used to drive the film.

(*e*) The second system, though more difficult to construct, has many advantages and in the authors' experience the extra effort involved in building this system is amply justified when a large number of spectra are to be taken.

ACKNOWLEDGEMENTS

Our thanks are due to our colleague, Mr. K. D. Outteridge, for making available to us his wide knowledge of electronic circuits involving fast rising pulses and for extensive assistance in the design of the circuit shown in Fig. 5.

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lectrometer for measuring the variation with concentration of the low frequency dielectric constant of aqueous ionic solutions

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A new electrometer is described which enables measurements to be made of the dielectric constants of aqueous ionic liquids, in terms of that of pure water, up to concentrations of about 10^{-2} N. The method depends on the observation of a null point when two couples acting upon an electrode suspended in the liquid are equal. One couple depends on electric forces and varies directly with the dielectric constant, whilst the other couple is magnetic and may be made proportional to the value of an external resistance. The probable error in the final results is of the order 0·5 %.

INTRODUCTION

knowledge of the variation of the dielectric constant of er as a function of the concentration of dissolved salts is great importance in research into the structure of water. ent work by the author(1) has shown that the diminution he dielectric constant of a saline solution, as more salt is ed, is proportional to the square root of the concentration, concentrations below 10^{-3} N. The square root law lies a widespread structural upheaval at a considerable ance from an ion, and this is borne out in the above work the fact that identical results are obtained for all the novalent chlorides from lithium to caesium, the size of positive ions having no detectable effect. The accuracy he work depends on a new electrical instrument which is lend of electrometer and electrodynamometer, and it is purpose of this paper to describe it in some detail.

FAILURE OF PREVIOUS METHODS

For non-conducting liquids, and for liquids with conductivities of the order 10^{-6} ohm^{-1} cm^{-1}, standard low frequency bridge techniques are adequate for measuring dielectric constant. For high conductivities, however, bridge methods at audio frequencies become quite impracticable because the conduction current through a test cell containing the liquid under investigation becomes very large in comparison with the displacement current. In any simple a.c. bridge therefore, the quadrature balance condition produces little or no change in the net detector current. At high frequencies, 10^6 c/s for instance, the situation is improved, but other difficulties associated with screening soon become overwhelming. Some of the best work in this field, carried out with high frequency bridges, was done by Sack,(2) but it is not possible to infer from these results the nature of the variation of the dielectric constant of water with the concentration of added salt because this is smaller than the experimental scatter.

In 1924 Fürth(3) devised an entirely new method of measuring the dielectric constant of conducting liquids, which involved the static measurement of the couple acting on a small ellipsoid suspended in the liquid when an electric field was acting through it. Pechhold,(4) using Fürth's apparatus, measured the dielectric constants of the chlorides of lithium, sodium and potassium. Once again, however, the scatter in these results was high, due in this case to the effect of thermal convection produced by the heating effect of the electric currents passing through the liquid. The great advantage of Fürth's technique was that it set out to measure something which was directly proportional to the property being investigated—that is to say, a couple which was directly proportional to the dielectric constant. In theory, at least for all practical concentrations, the conductivity of the liquid in no way affects this property, whereas in bridge techniques the conductivity so reduces the sensitivity of the bridge to capacitance changes that such methods become completely unreliable. Unfortunately, Fürth's method is spoiled by the indirect effect of conductivity, namely local heating due to the passage of current.

PRINCIPLE OF APPARATUS

The present electrometer overcomes the drawback associated with Fürth's instrument by balancing the electric couple, produced on an electrode suspended in the liquid when an electric field acts, by a magnetic couple produced by currents flowing in a system of coils. In this way a null balance may be obtained before convection streaming has started. The general principle of operation may be gathered from Fig. 1. Coils X and Y constitute a dynamometer, and coil Y is rigidly fixed to the electrode $BCC'B'$, the whole being suspended in the liquid, the current leads to Y being suitably insulated, and a key K being provided. Electrodes A and A' are fixed near to B and B' so that when a potential difference of V V r.m.s. is applied between A and A', there is an electric couple T_E acting on BB', given by

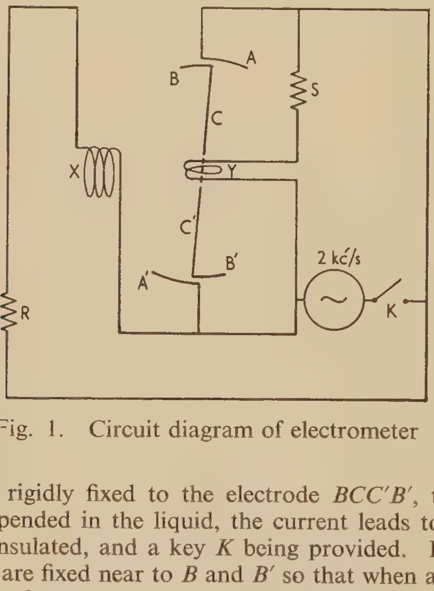

Fig. 1. Circuit diagram of electrometer

$$T_E = \frac{\varepsilon V^2}{18 \times 10^4} \frac{\partial C}{\partial \theta} \text{dyne cm} \qquad (1)$$

where C is the air or vacuum capacitance in e.s.u. between A and A' as a function of the position θ of BB'.

According to Fig. 1, if i_x and i_y are the r.m.s. values of currents flowing in the coils X and Y, and if ϕ is the ph difference between them, then the magnetic couple between and Y is given by

$$T_M = i_x i_y \cos \phi \, \partial M_{xy}/\partial \theta$$

where M_{xy} is the mutual inductance between X and Y.

Now i_x and i_y are both produced by V, the applied volta and provided the resistance S in series with Y is very la compared with the reactance of Y, and provided R is consta equation (2) may be written

$$T_M = \frac{V^2 F}{S} \partial M_{xy}/\partial \theta$$

where F involves cos ϕ, reactance terms and units conversi factors. It is assumed that S includes the resistance of and R includes the resistance of X. If a balance is obtain between T_E and T_M, it follows that, from equations (1) and

$$\varepsilon = \frac{F'}{S} \frac{\partial M_{xy}/\partial \theta}{\partial C/\partial \theta}$$

where F' absorbs F, V, and numerical constants.

In practice, measurements are all made at a constant va of θ, but in any case $\partial M_{xy}/\partial \theta$ is constant for small deviati of θ about its zero, provided coils X and Y are initiall right angles to each other. If the capacitance between and A' is made to follow a linear law with θ, which is t case if A and A' and B and B' are parallel plates, then ∂C is also constant for small excursions of θ about the mark. Under these circumstances, the last equation beco

$$\varepsilon = F''/S$$

where F'' is a constant of the apparatus. If a prelimina experiment is performed on pure water, whose dielect constant is ε_0, then

$$\varepsilon_0 = F''/S_0$$

whence, by substitution for F''

$$\varepsilon = \varepsilon_0 S_0/S$$

Equation (4) is the experimental equation, and t important thing about it is that the dielectric constant of solution may be obtained in terms of the dielectric consta of a standard and the ratio of two resistances. The ancilla apparatus is a 2 kc/s oscillator of good frequency stabili ($\pm 0{\cdot}1\%$), capable of maintaining about 40 V between and A' for the whole range of conductivity values involv in a given investigation. Since the method is a null metho the amplitude of the applied e.m.f. need not be stabilize and it need only be applied for a very short time since t motion of BB' is instantaneous under the influence of exce magnetic or electric couples, whereas the agitation due convection currents takes a little time to develop.

DETAILS OF CONSTRUCTION

The general constructional details may be gathered fro Fig. 2. The electrical system is similarly lettered in Figs. 2 and 3. The platinum static electrodes A and A', coat with platinum black, were mounted as shown in Fig. 2 the inside walls of a flat box (1) made of 1 × $\frac{1}{4}$ in. Persp strip. The back of the box consisted of a 7 × 7$\frac{1}{2}$ × $\frac{1}{8}$ Perspex sheet (3) which was welded into position, usi chloroform as a solvent. Stuck to the back of this she was a rectangular frame (4), also of $\frac{1}{8}$ in. Perspex shee lowed by another sheet (5) identical to (3) but carrying › Perspex tubes (6). This structure, in conjunction with a nilar one in the lid (7) of the box, constituted an efficient ter jacket and made it possible to stabilize the temperature the apparatus to within $\frac{1}{10}$° C of 25° C. The stator coils were wound on formers made from Perspex disks 2 in. in meter and $\frac{1}{4}$ in. thick, with $4\frac{1}{2}$ in. diameter disks of $\frac{1}{8}$ in. rspex sheet stuck on either side; the $1\frac{1}{4}$ in. deep by $\frac{1}{4}$ in. le winding spaces were filled with 24 s.w.g. enamelled pper wire and the two coils were stuck symmetrically one the back and one on the lid of the box, as shown in Fig. 2.

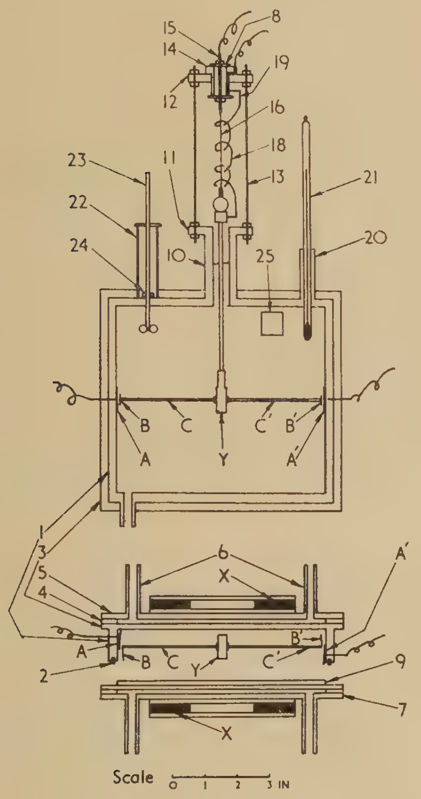

Fig. 2. Plan and elevation of main assembly

slot (2) $\frac{1}{8}$ in. wide was milled in the edge of the box (1), d this was filled with two strands of $\frac{1}{16}$ in square elastic. vo strands were used in order that the joints in each would overlapped, thus ensuring a water-tight seal when the lid s clamped to the box by means of simple clamps made of fnol strip and 2 B.A. screws. The lid was located with pect to the box by means of a Perspex strip (9) which ed snugly along the bottom inside edge of (1).

The top of the box carried a superstructure for supporting moving electrode build up from a 2 in. length of 1 in. ameter Perspex rod (10) bored out to form a tube of $\frac{1}{2}$ in. ernal diameter. Surmounting this, a Perspex disk (11) n. in diameter and $\frac{1}{4}$ in. thick supported a similar disk (12) means of three lengths of 2 B.A. studding (13), fixed by ts to (11) and (12). A brass bush (14), $\frac{1}{2}$ in. in diameter h a thick $\frac{1}{4}$ in. flange, passed through the centre of (12) d supported a length of 6 B.A. studding (15) which was mped to (14) by means of nuts compressing the Paxolin shers (8) and (17). The lower end of (15) was filed flat, d to this was soldered the phosphor–bronze ribbon (16) pporting the moving electrode assembly and supplying current to coil Y. The return lead from coil Y was taken through a loose helix (18) of phosphor–bronze wire and soldered to a Terry clip (19) which was clamped to the bush (14). External connexions were thus made to Y via (14) and (15).

In addition to the above superstructure, the top of the box carried a Perspex tube (20) for supporting the thermometer (21), and a further tube (22) which acted as a support for the glass stirrer (23), an O-ring seal (24) being incorporated at the point where the stirrer entered the box. In order to keep a check on the conductivity of the liquids under investigation, two platinum electrodes (25) (one of which is shown) were incorporated, one on the inside surface (3) of the back of the box and the other on the inside surface of the lid immediately facing it. These electrodes were connected to a conductivity bridge. The electrodes A and A' were of platinum foil, 2 cm long vertically and $1\frac{1}{2}$ cm wide, as in the plan view of Fig. 2. Each electrode was bent to form parts of the surface of a circular cylinder whose axis coincided with the vertical axis of the instrument; each was then glued to a piece of Perspex, similarly curved on one side, and stuck to the inside wall of the instrument, as shown in Fig. 2, exactly halfway down the sides of the box (1), A with a 2 cm edge in contact with the back (3) of the box, and A' with a 2 cm edge in contact with the lid. Two copper wires soldered to these electrodes were fused through the Perspex sides of (1) and served to make connexions with the external circuit.

The construction of the suspended system will be better understood by reference to Fig. 3. The essential requirement about this part of the apparatus was that coil Y and the leads to it should be completely insulated from the liquid. A small Perspex pill box (26) was turned, with wall thickness of 1 mm and external diameter and height 2 cm and 8 mm respectively. Firmly glued within this was coil Y, consisting of 1000 turns of 44 s.w.g. enamelled copper wire wound on a bobbin (27) 18 mm across and 6 mm high. The leads to the coil were pushed through a small hole (28) in the side of (26) and the lid (29) was firmly glued in place. When this structure was quite firm, a brass tube (30), threaded 6 B.A., was force-fitted through the centre of the coil assembly, and a short Perspex tube (31), shaped at the lower end, was stuck to (26) immediately above the hole (28). The leads to coil Y were threaded through a small glass tube (32), the lower end of

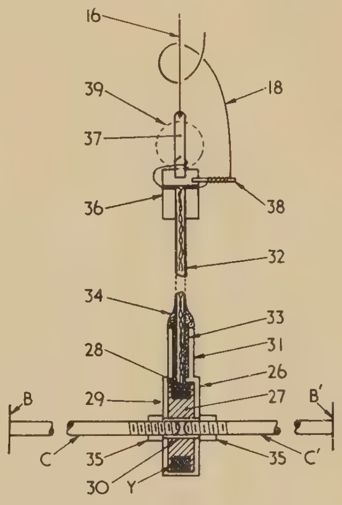

Fig. 3. The suspended electrode assembly

which was forced into (31), a polythene sleeve (33) acting as a water seal. Before (32) was forced into (31), however, the capsule was thoroughly warmed in a stream of hot air, and, whilst it was still hot, soft molten red wax was poured into (31). Tube (32) and sleeve (33) were then fitted and, finally, a seal of Chatterton compound (34) was provided above the sleeve.

The moving electrode $B\ C\ C'\ B'$ was made in two parts, BC and $C'B'$, each consisting of 1 × 1½ cm platinum plates coated with platinum black, soldered to the ends of 3 in. lengths of stiff brass rod, threaded 6 B.A. at the other end and equipped with a lock nut (35). These assemblies were screwed into (30), and clamped by means of (35) in the position shown in Figs. 2 and 3, the clearances between A and B and between A' and B' being about 1 mm. The attachment of the top end of the tube (32) to the phosphor-bronze suspension was carried out by using a polythene cap (36) equipped with two brass lugs (37 and 38). The wires from Y were soldered to these lugs, having passed first through two small holes in the cap as shown, the cap was then forced tightly over the end of (32). The suspension ribbon (16) was soldered to lug (37), which also carried a galvanometer mirror (39), and the return lead from Y passed *via* lug (38) through helix (18) to the Terry clip (19). Prior to assembly, a thin layer of silicone tap grease was spread over all the metal surfaces associated with the moving system, with the exception of the blackened surfaces of the platinum electrodes.

EXPERIMENTAL PROCEDURE AT 2 KC/S

With the circuit connected according to Fig. 1, the key K was pressed momentarily and the direction of the initial deflexion of a beam of light reflected from mirror (39) was noted. Resistance S was adjusted until no initial movement of the beam was observed at the instant of closing key K. This represented a condition which satisfied equation (4). For this experiment the cell was filled with boiled out distilled water. The concentration was then increased by injecting a measured quantity of N/2 salt solution into the apparatus *via* tube (20) (Fig. 2) which supports the thermometer. The stirrer (23) was then set running until the readings given by a conductivity bridge connected to the conductivity electrodes (25) were steady. The stirrer was stopped and the suspended electrode allowed to come to rest. The indicator spot was brought to its zero, if necessary, by turning the torsion head (14) (Fig. 2), and a test for balance was made by closing key K. As mentioned above, there is an instantaneous deflexion due to the unbalanced torque, which followed up by the convection effect produced by loc heating. It was always found possible to bracket the balan point to within 0·5% of the value of S, even when deali with high concentrations of the order 10^{-2} N, which h conductivities in the region $2 \times 10^{-3}\ \text{ohm}^{-1}\ \text{cm}^{-1}$. T bracketing process took some time because it was necessa to let the convection currents produced at every trial balan die away.

Sodium chloride solutions at 25° C

Concentration (milliequivalent wts/litre)	Conductivity (ohm^{-1} cm^{-1} × 10)^6	$S/(\Omega)$ S_{min}	S_{max}	$\frac{100\,S_0}{S} = \frac{\varepsilon}{\varepsilon_0}$ (%)	Maximum % spread in $\varepsilon/\varepsilon_0$
0·0	0·2	8340	8360		
0·08	13·6	8430	8470	98·9	±0·4
0·17	24·7	8480	8520	98·3	±0·4
0·34	46·0	5530	8580	97·7	±0·5
0·67	89·0	8600	8670	96·8	±0·6
1·34	173·0	8700	8770	95·8	±0·6
2·69	334·0	8860	8940	93·9	±0·6
5·02	604·0	8980	9060	92·6	±0·6
9·22	1058·0	9100	9200	91·3	±0·7
13·4	1490·0	9150	9250	90·8	±0·7

The above table constitutes a typical set of results f sodium chloride solutions. The values of the contr resistance S in columns 3 and 4 include the resistance of c Y. Columns 3 and 4 represent the values of S at which t initial movement of the suspended system indicates wi certainty that the electric couple is smaller or larger respe tively than the magnetic couple. It is convenient in this wo to consider the ratio of the dielectric constant of the solutio to that of pure water. This is given by the ratio S_0 to where S_0 refers to the value of S for pure water. As th above data indicate, the probable error in this ratio nev approaches ±0·5%. When further results are taken aft dismantling and reassembling the apparatus, the net probab error still lies below ±0·5%, even if the electrodes a deliberately given a slight twist so as completely to alter th character of the convection effects.

The constant F of equation (3) is frequency dependent to th extent that a 5% change in supply frequency causes a 1 variation in the balance. The present work was carried o with a supply frequency of 2 kc/s, the stability of which w better than 0·1%. As implied by the theory, the bala point was found to be independent of the voltage amplit of the source, but since the sensitivity of the system is pr portional to the square of the applied voltage amplitud this was made as large as possible and amounted to abo 40 V r.m.s.

CONCLUSION

The results obtained with this electrometer show the sam initial trend as those of Pechhold[(4)] but, unlike the latte do not show an increase in the dielectric constant at concen trations greater than 0·006 N. In the opinion of the autho this increase is spurious and can be accounted for in terms o convection effects. In the present apparatus this source o error is greatly reduced.

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Large scale laboratory freeze-drying apparatus

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[*Paper first received* 28 *July, and in final form* 29 *September*, 1958]

An apparatus is described which will freeze-dry a total of 6 l. of solution distribution in twenty flasks each twenty-four hours, with a minimum of attention and at a low operating cost.

e apparatus described has been constructed to the authors' wn requirements for a general purpose laboratory apparatus. e general appearance is shown in Fig. 1 and an internal ew in Fig. 2. The apparatus consists of an Edwards type C150A gas-ballasted two-stage vacuum pump, connected, y an automatic 1 in. diameter magnetic shut-off and air dmittance valve, to a vacuum drum. The drum in turn is onnected to a 3 in. diameter copper manifold. Inside the rum is a coil, cooled by a Prestcold air-cooled $\frac{3}{4}$ h.p. low-emperature refrigeration unit, which freezes out the water vaporating from the solutions under treatment. The anifold divides into two parallel 1·5 in. diameter tubes, ngth 60 in., connected to nine B29 ground metal cones. hese cones connect to glass T-tap units (tap bore 15 mm) with from one to three B24 cone inlets to which a total of twenty flasks may be attached. The tap and inlet cone arrangement may be readily redesigned to alternative requirements. The electrical and mechanical design is shown schematically in Fig. 3.

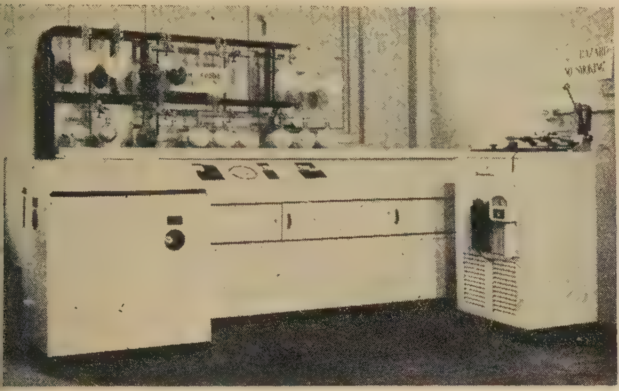


Fig. 1. General view of freeze-drying apparatus

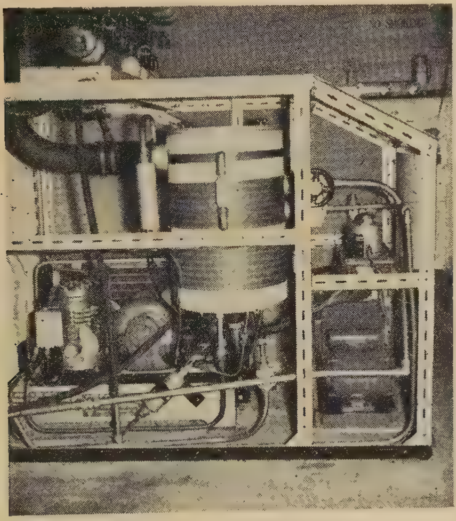
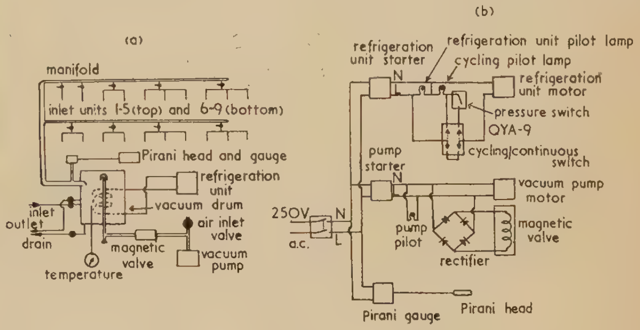


Fig. 2. Internal view of freeze-drying apparatus

Adequate instrumentation has been incorporated. The temperature of the refrigerated coil in the vacuum drum is displayed on a dial type thermometer. The pressure at the junction of the manifold and the vacuum drum is detected by an Edwards type M5B-1 pressure gauge head and a type 7-1B dual-range Pirani vacuum gauge (by Edwards High Vacuum Ltd.). Power supply is controlled by two dash-pot overload protection switches. The operation of the vacuum and refrigerator unit motors is indicated by lights on the control panel, with an additional warning light for the "cycling" state of the refrigeration unit. The cycling switch introduces a type QYA-9 pressure switch (by Edwards High Vacuum Ltd.) into the refrigerator unit circuit to ensure operation of the unit at intervals, this preventing leakage of the refrigerant through the bearings and simultaneous extrusion of lubricant from the bearings.



(a)
manifold
inlet units 1-5 (top) and 6-9 (bottom)
Pirani head and gauge
refrigeration unit
vacuum drum
air inlet valve
inlet
outlet
drain
magnetic valve
vacuum pump
temperature
(b)
refrigeration unit starter
refrigeration unit pilot lamp
cycling pilot lamp
N
refrigeration unit motor
pressure switch QYA-9
cycling/continuous switch
pump starter
N
vacuum pump motor
250V a.c.
N
L
pump pilot
rectifier
magnetic valve
Pirani gauge
Pirani head

Fig. 3. Schematic diagrams

(*a*) Schematic mechanical diagram.
(*b*) Schematic electrical circuit.
N, neutral; *L*, live.

The apparatus has been enclosed with hardboard supported on a Handy Angle L-section metal structure. Sliding panels give easy access to the working parts, and provision for adequate air circulation has been made.

Defrosting of the vacuum drum is effected by passing water through the drum. Water inlet, outlet and drainage valves are connected to the drum, and the defrosting process is as described for the Edwards model 30P freeze-drying unit.

Provision for the rapid pre-freezing of solutions to the inside of the flasks is essential. This requirement has been satisfied by adapting a Frigidaire model LT-26 low-temperature thermostatic storage cabinet. The cabinet has been filled with fifteen gallons of industrial ethanol. The indicating thermostat lead was taken over the top of the inner tank to prevent leakage of the contents through the lead hole, which was then blocked by a bung. It has been found that a temperature of −35 to −40° C is suitable for this tank. An adjustable device for spinning up to three flasks at variable speeds at an angle in the coolant has been attached to the top of the cabinet (Fig. 4). The flask spinners are driven by a Parvalux electric motor (250 V, a.c., controlled by a 150 Ω, 1 A rheostat) through a reduction gearbox with maximum output 250 rev/min and 25 lb/in. torque.

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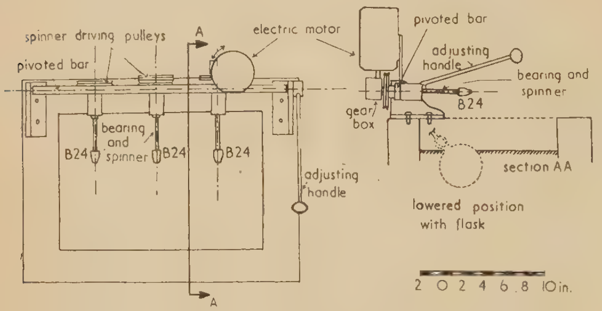


Fig. 4. Construction diagrams of pre-freezer unit

PERFORMANCE DATA

Operating pressure. Minimum 0·05 mm, maximum 0·7 mm. (Normal during drying 0·2–0·5 mm.)

Operating temperature. Minimum −50° C, maximum −15° C. (Normal during drying −30 to −40° C.)

Condenser drum ice load. Maximum 10 l., optimum 8 l.

Freeze drying times in 1 l. glass flasks containing 5 sucrose solution.

Solution volume (ml.)	50	100	200	300
Drying time (mean) (h)	3	5	9	15

Defrosting. Time required for 8 l. load at −50° C, defro water inlet temperature 15° C: 30 min.

Starting times. (*a*) Drum dry, (*b*) drum wet (as aft defrosting).

Cool down, room temperature to −20° C, (*a*) 15 mi (*b*) 15 min.

Pump down, 1 atm to 0·5 mm, (*a*) 5 min, (*b*) 15 min.

Pre-freezer unit operation. 1 l. flasks containing 250 m water at 15° C initially.

Bath temperature (°C)	−40	−30	−20	−1
Freezing time (mean) (min)	4	7	13	2

The authors would be pleased to answer any furthe queries concerning the apparatus.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. M. Stacey for hi interest. They would also like to thank Mr. Sellars and M Sheard of this department for technical assistance a Edwards High Vacuum Ltd. for their ready co-operation.

Cryostat for measuring the electrical properties of high resistance semiconductors at low temperatures

By W. H. Mitchell and E. H. Putley, B.Sc., Ph.D., A.Inst.P., Royal Radar Establishment, Malvern, Worcestershi

[*Paper received* 22 *May*, 1958]

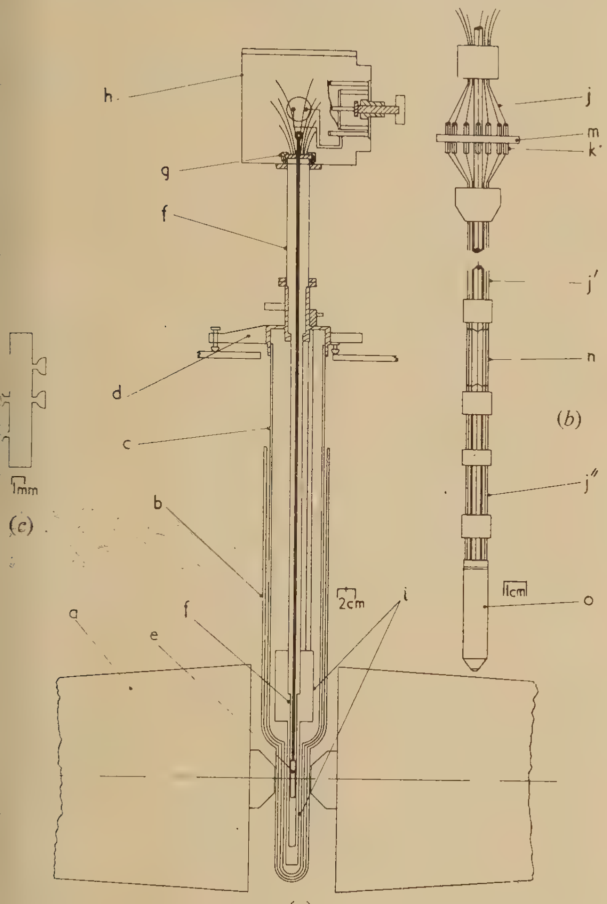
This apparatus enables measurements to be made on semiconductors of resistance up to 10^{11} Ω at temperatures down to 2° K. A vibrating reed electrometer is used for the measurements. The characteristics of suitable instruments are described and the performanee of the apparatus is illustrated by showing some results obtained for a specimen of gold doped silicon. The maximum specimen resistance which can be used is determined by the self-capacity of the apparatus. The noise level in the electrometers sets a lower limit for the measurement of Hall mobility at about 10 cm^2 V^{-1} s^{-1}.

DESCRIPTION OF APPARATUS

The resistance of the purest samples of some semiconductors may rise to values of 10^9 Ω and higher upon cooling below room temperature. Resistances in this range have been encountered in germanium,$^{(1, 2)}$ silicon$^{(3, 4)}$ and indium antimonide.$^{(5)}$ The temperature at which the resistance rises to this level depends both on the semiconductor and the type of impurity present. Thus, for germanium and indium antimonide, temperatures below 10° K are required. For silicon doped with impurities from groups III or V, temperatures below 50° K are required, but with silicon doped with some other impurities, for example gold, resistances of 10^{11} Ω can be obtained at 200° K.

The apparatus described was designed for measuring the electrical conductivity and Hall coefficient of this high resistance material from temperatures below 2° K up to 300° K. The cryostat is of conventional design. Considerable care was taken in designing the specimen holder to avoid leakage currents. Measurements are made using a vibrating reed electrometer.$^{(6)}$ Care has been taken with the associated circuits to ensure perfect screening and a high leakage resistance.

Fig. 1(*a*) is a diagram of the cryostat. It is designed to be placed between the poles of an electromagnet *a*. The outer Dewar vessel *b* contains liquid nitrogen (only required when helium is used). The inner Dewar vessel *c*, fitting into the Dewar cap *d*, contains the refrigerant (liquid helium, hydrogen or others as required). When helium is used the space between the walls of the Dewar vessel *c* is filled with air at a pressure of 1 mm. This assists in the pre-cooling of the apparatus by the liquid nitrogen in the outer Dewar vessel, but on filling Dewar vessel *c* with liquid helium the air freezes and the Dewar vessel then functions as a normal hard Dewar vessel. The specimen holder *e* is placed inside the central tube which runs the length of the apparatus, and at the top the tube is sealed by means of an O-ring and a nut *g*. The tube *f* is extended sufficiently above the Dewar cap *d* to avoid any possibility of condensation or icing on the leads emerging from the crystal holder. A copper can *h* is mounted on top of the tube *f* to screen the connexions to the specimen holder. The lower part of the tube *f* is enclosed by a case *i*. When the apparatus is in use the inner tube *f* is filled with helium at reduced pressure as thermal exchange gas. The outer case *i* may either be filled with exchange gas it may be pumped to a vacuum of about 10^{-5} mm of rcury. When the outer case is filled with exchange gas specimen holder will assume the temperature of the bath, t when the case is pumped out it is possible to raise the nperature of the specimen above that of the bath by means a heater coil wound round the lower part of tube *f*. To ilitate this arrangement the tube *f* is made in two parts. om the top of the apparatus down to about one inch inside can *i*, the tube is made of cupro-nickel to reduce the heat ansfer down it, but the lower part is made of high conctivity copper to ensure good thermal coupling between e specimen and the heating coils. With this arrangement is possible to work at any desired temperature from about 7° K (obtained by pumping the helium) up to room mperature.



(*a*)

Fig. 1. (*a*) Section of cryostat. (*b*) Specimen holder. (*c*) Plan of specimen

Temperatures are measured by vapour pressure of the frigerant when possible, or by platinum resistance thermoeters above 20° K. Below 20° K carbon resistance thermoeters are used.(7) The platinum thermometer is wound on e copper outer tube of the specimen holder *e*. The carbon ermometer is mounted inside the holder *e*. Thermal upling between the thermometers and the specimen is hieved by the presence of exchange gas inside tube *f* which sures that the small copper specimen holder *e* forms a nstant temperature enclosure.

Fig. 1(*b*) shows a diagram of the specimen holder. The res *j j′ j″* leading to the specimen are supported by polyrafluorethylene insulators. A vacuum seal was made by passing each wire through a fused quartz tube *k*. These tubes are sealed with vacuum wax into the brass plate *m* and the wires are waxed into the tubes. The brass plate *m* also serves to close the top of the inner tube of the cryostat and to support the crystal holder. To reduce to a minimum heat conducted down the specimen holder, the polytetrafluorethylene insulators are supported on a central tube of cupro-nickel. The lead wires are of copper 0·002 in. in diameter. It is desirable to attach lead wires to a heat sink before they reach the specimen to ensure that any heat conducted down them cannot warm the specimen above the temperature of its enclosure. In an apparatus for studying low resistance materials this is easily achieved by wrapping the leads round some part of the apparatus in contact with the refrigerant, but this is not possible here. A heat sink *n* was devised by attaching a vane of copper foil to each wire just above the top of the outer can of the cryostat. The vanes were about 5 cm long by 0·5 cm wide. It was estimated that heat conducted down the leads would be dissipated at these vanes by convection currents in the exchange gas filling the inner tube. The specimen holder is terminated by a small copper can *o* which encloses the specimen and the thermometers. The specimen holder was tested by placing in the can a known resistance of between 10^{10} and 10^{11} Ω in value and measuring the resistance between the leads at the top of the holder. It was found that the shunting effect of the holder could not be detected.

Specimens are usually prepared of the shape shown in Fig. 1(*c*). This shape is cut out of a plate of the material by means of an ultrasonic cutter. Connexions can then be made at the ends and at the tips of the side arms without the risk of the contact material shunting the high resistance of the central portion of the specimen. The method of making contacts depends on the semiconductor, but the authors have used aluminium alloyed junctions to *p*-type silicon and germanium, gold–antimony alloy for *n*-type silicon and germanium, and indium solder to indium antimonide.

METHOD OF MEASUREMENT AND PERFORMANCE

Fig. 2 shows a schematic diagram of the measuring circuit. Current from the battery *B* is fed *via* a reversing switch *V* and a calibrated resistor *R* through the specimen. By adjusting the tappings of the battery and of the potential divider *P*, it is possible to adjust the potential applied to the specimen from several hundred volts down to a few millivolts. This facility is useful for studying the dependence of the conductivity and Hall effect upon electric fields. The current passing through the specimen is determined by measuring the voltage across the calibrated resistor *R*. The resistance of the specimen is then found by measuring the potential drop across the outer pair of potential contacts while the

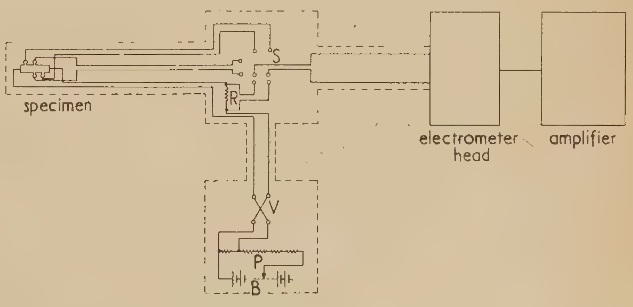


Fig. 2. Measuring circuit

central pair of potential contacts are used for measuring the Hall voltage. The potential measurements are made by connecting the circuits to the electrometer by means of the selector switch *S*. Measurements are made in pairs, with current being reversed by means of the switch *V*.

Considerable care has been taken in the design and arrangement of the components used in this circuit. The dotted line in Fig. 2 denotes a continuous metal screening can which encloses the whole circuit. The battery *B* and the resistors *P* and *R* are mounted on polytetrafluorethylene pillars. The selector and reversing switches were specially designed. The contact studs are mounted on distrene pillars about two inches long. Contact between appropriate studs is made by wiper arms which are rotated into position by means of a distrene rod attached to a metal shaft which is a good fit in a bearing mounted on the side of the screening box. In this way all parts of the switch are isolated from each other and from earth, but the switch movement can be effected without breaking the screening. The resistor *R* and the selector switch are mounted in the screening box on the top of the cryostat. A sectional view of the switch is shown in Fig. 1(*a*). The battery and the reversing switch are mounted in a second box. Connexions between the two boxes and from the selector switch to the electrometer head are made using twin screen connectors, the outers being made of brass tubing and the inners of rigid rods supported independently by distrene spacers. Checks on the performance of this system show that the limiting factor determining the maximum resistance which can be conveniently measured is not the leakage resistance of the components, but the self-capacity of the circuit. This capacity is such that the time required to take a measurement on a specimen of $10^{11}\ \Omega$ resistance is two or three minutes. This is as long as is generally convenient to allow, and therefore $10^{11}\ \Omega$ can be taken as the upper limit of resistance which can be dealt with.

The voltages are measured by means of a vibrating reed electrometer. This consists of two units; the head, which contains the dynamic condenser element and a pre-amplifier, and the main amplifier. A high level of negative feedback is employed, so that the behaviour of the instrument approaches very closely that of a true null system, such as a potentiometer. Since the input resistance of these instruments is of $10^{15}\ \Omega$ or higher, the current drain of the instrument will be negligible and therefore it can be used as a direct-reading voltmeter. If preferred, it can be used as the null detector in a potentiometer system. The voltage sensitivity is determined, when short term stability only is important, by the noise level of the instrument. Tests made on three types of instrument gave the following results. Carbon resistors were used for the source resistance.

Source resistance (Ω)	*Applied Physics Corp. Model 31*	*Electronic Instruments Ltd. Vibron Model 33 C*	*A.E.R.C. type 1086 C*
		Signal = noise (μV)	
shorted	<10	30	30
10^9	10	40	30
10^{10}	25	50	60
10^{12}	50	—	—

Thus it is seen that resistances below $10^9\ \Omega$ can be regarded as short circuits as far as these electrometers are concerned. For higher resistances the noise level includes a contribution from the source. These results indicate that when the instrument is used to measure the Hall voltage from a $10^{11}\ \Omega$ specimen, a voltage of about 50 μV should be detectable with the best available instrument. Assuming that the maximum field which could be applied to the specimen was 1 V/c then for a specimen of the dimensions shown in Fig. 1(*c*) t conductivity σ would be of the order of $10^{-9}\ \Omega^{-1}\ \mathrm{cm}^{-1}$, t Hall coefficient R $10^9\ \mathrm{cm}^3\ \mathrm{c}^{-1}$ and hence the Hall mobil $R\sigma$, which can be regarded as a figure of merit for the p formance of the system, would be of the order of uni This argument assumes that the noise and stability of t specimen will be comparable with that of the resistors us for these tests. In general, this is not borne out in practic A more realistic lower limit for the mobility is abo $10\ \mathrm{cm}^2\ \mathrm{V}^{-1}\ \mathrm{s}^{-1}$. Values of this order have been observ in indium antimonide at 4° K. Results obtained with th apparatus have been described elsewhere,(4, 5) but Fig. shows results obtained from a gold-doped silicon specimen the resistance of which was about $10^{11}\ \Omega$ at 200° K but whic fell exponentially to about $10^3\ \Omega$ at 500° K. The data abov room temperature were obtained from a simplified versio of the apparatus which could be placed inside an oil bath.

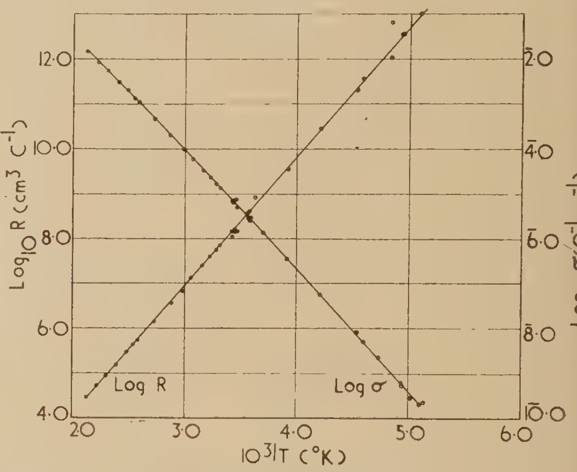


Fig. 3. Hall coefficient and conductivity of a sample of gold-doped silicon

To conclude, this apparatus is suitable for measuring th properties of semiconductors of resistance up to $10^{11}\ \Omega$ and with Hall mobilities down to $1\text{–}10\ \mathrm{cm}^2\ \mathrm{V}^{-1}\ \mathrm{s}^{-1}$ over th temperature range 2 to 300° K. A simplified version of th apparatus has also been designed for use above room temperature.

ACKNOWLEDGEMENTS

We should like to thank Dr. D. H. Parkinson for many helpful discussions concerning the design of this apparatus. This paper is published by permission of The Controller, H.M. Stationery Office.

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Method of determining the dynamic constants of liquid-containing membrane manometer systems

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An instrument with which to produce sine and square wave changes in pressure in the hydraulic systems of membrane manometers is described. It consists of a cylindrical chamber to one end of which a metal membrane is secured; fixed to the membrane is a barium titanate strain gauge which, when energized by alternating voltages, causes alternating pressure changes in the chamber. The theory on which the construction of this instrument is based is substantiated by experiment. The use of the instrument in the examination of a damped capacitance manometer system is described.

INTRODUCTION

embrane manometer systems are used to record blood essure in man and animals. An expression of the accuracy th which such manometers translate the pressure change the vessel or chamber of the heart into an inscribed essure pulse contour must include a measure of the response that manometer system, not only to static stepwise changes pressure, but to square wave or sine wave changes in essure.

Previously, to provide a square wave pressure front it has en necessary suddenly to remove a pressure source from manometer system to be tested; e.g. a balloon attached the manometer system was inflated and then ruptured by a ow torch (Wood(1)), or, the piston was rapidly removed om a syringe which was connected to the manometer ansen(2)); both of these methods are unsatisfactory because ovements may be imparted to the whole system of metal bes and clamps as well as to the fluid column. Sine wave essure changes were produced by Buchthal and Warburg(3) d Lambert and Jones(4) with an instrument based on ernating movements of a piston, and by Hansen(2) who ed a large electromagnetic pump. With these instruments amplitude of the pressure variation increased with the crease in frequency of oscillation. Skouby(5) used a pacitor microphone, similar in principle to that described Wente(6) to produce sound waves, but the variations in essure were small. Isaacson and Jones(7) used an electroagnetic drive unit to move a membrane attached to a amber and monitored the pressure changes in the chamber th a strain gauge manometer. But with an electromagnetic ive unit true sine wave variations may not be produced at w frequencies.

The instrument described here is easy to construct, simple use and it will generate both square wave and sine wave essure pulses; although it is necessary to have available the propriate electronic devices to provide square and sine ave changes in voltage input to the generator.

INCIPLE AND DESCRIPTION OF THE INSTRUMENT

The instrument consists of a cylindrical chamber to one d of which a metal membrane is attached; at the other d is an outlet which is connected to the pressure measuring vice to be tested. A barium titanate strain gauge (General ectric Co. Ltd.) is fixed (using Durofix, Rawlplug Co. Ltd.) the surface of the membrane. Sine wave changes in pressure are set up in the chamber by sine wave changes in voltage across two surfaces of the piezo-electric strain gauge. The advantage of this method of producing pressure changes is that the construction of the instrument can be based on the manometer theory of Frank(8) and on formulae which indicate the behaviour of circular metal plates under stress (Roark(9)).

A diagram of the construction of the pressure wave generator is shown in Fig. 1. The internal diameters of the generator chamber G and the spacing ring D were identical and exactly opposed to obtain accurately the desired free diameter of the membrane. The membrane was clamped in position by a screw mechanism because "buckling" occurred when a thin membrane of large diameter was attached by means of hot setting adhesives such as solder or resin. The barium titanate strain gauge was fixed across the middle of the membrane with Durofix; at least five days were allowed for the Durofix to set before the instrument was used.

Sine wave and square wave voltage changes across two surfaces of the strain gauge were obtained from instruments available in the laboratory. The source of sine wave voltage change was a Type L. O. 800A oscillator, 0 to 25 000 c/s (Birmingham Sound Reproducers Ltd.) using the resistance capacity output stage and subsequent d.c. amplification which provided an input voltage of 70 to 80 V to the strain gauge. With this input voltage the pressure variations were small—of the order of 20 to 30 cm of water; the actual value depended on the volume of liquid in the manometer system, but manometer systems should give an adequate record with such pressure variations. The maximum permissible input voltage to the strain gauge is 200 V, but such a supply was not immediately available. A square wave input of 70 to 80 V to the strain gauge was obtained from a commercial stimulator using pulses of 100 ms duration 1·5 times/s.

THEORY

It is important first to consider whether attaching some device to the manometer system alters the characteristics, in terms of the undamped natural frequency, of that system.

A manometer system may be shown to be a single degree of freedom system analogous to a simple spring-mass system (Noble(10)); and the undamped natural frequency f_n of the manometer system may be expressed as

$$f_n = \frac{1}{2\pi} \cdot \sqrt{\frac{E}{M}} \qquad (1)$$

where M is the effective mass of the fluid in the system and E is the volume elasticity coefficient as defined by Frank.(8)

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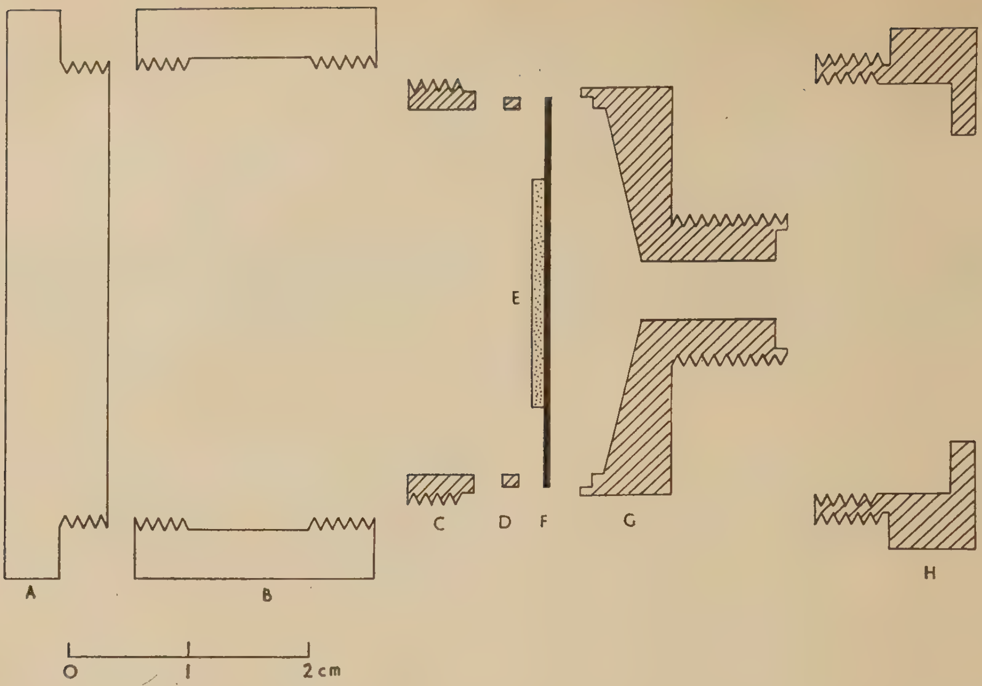

Fig. 1. Diagram of the pressure wave generator

A, *B*, Perspex cover; *C*, screw clamping ring; *D*, spacing ring; *E*, barium titanate strain gauge; *F*, beryllium copper membrane; *G*, generator chamber; *H*, holding ring. *C*, *D*, *G* and *H* were made of brass. Membrane *F* was sealed to spacing ring *D* and chamber *G* with a cold setting adhesive immediately before tightening up the screw clamping ring *C*. Leads from the strain gauge *E* were soldered to terminals (not shown) inserted radially through the Perspex cover *B*.

Although the generator when not attached to the manometer has a separate volume elasticity coefficient E_1 and effective mass M_1, when joined to the pressure generator the effective mass of the combined system is equal to the sum of the two masses because the liquid in both systems is in continuity; it is suggested that a spring-mass system analogous to this combined system is one consisting of one mass and two springs arranged in "parallel" (Fig. 2). Such a system is also a single degree of freedom system (Den Hartog$^{(11)}$) and its undamped natural frequency $f_n(S)$ is given by

$$f_n(S) = \frac{1}{2\pi} \cdot \sqrt{\frac{k_1 + k_2}{m}} \qquad (2)$$

where k_1 and k_2 are the spring constants and m is the mass. From this analogy it may be inferred that the undamped natural frequency $f_n(C)$ of the combined generator–manometer system will be given by

$$f_n(C) = \frac{1}{2\pi} \cdot \sqrt{\frac{E + E_1}{(M + M_2)}} \qquad (3)$$

where E and E_1 are the volume elasticity coefficients of the manometer system and the generator and $(M + M_1)$ is the effective mass of the combined systems (equal to the sum of the two effective masses).

Comparing equation (3) with equation (1) it is seen that the natural frequency of the combined manometer-generator system will only be equal to the natural frequency of the manometer system if the values of the effective mass M_1 and the volume elasticity coefficient E_1 of the generator are small compared with those of the manometer system. In practice, because the chamber and the connecting tube of the pressure generator are short and of large bore the effective mass the liquid in the generator is small compared with that any manometer system to be tested. Therefore, when co structing a pressure generator it is necessary only to consid the volume elasticity coefficient of the generator. It may l shown from equations (1) and (3) that the natural freque of the combined system will be within 1% of that of tl manometer system alone if the volume elasticity coefficie of the generator is not greater than 2% of the volume ela ticity coefficient of the manometer system. Knowing th volume elasticity coefficient of the manometer to be teste and thus of the generator to be constructed, the dimensio of the generator may be calculated. Ignoring the compre

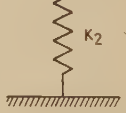

Fig. 2. Mass-two spring system analogous to the combined generator-manometer system

k_1 and k_2, spring constants; m, mass ility of the small amount of liquid in the generator, the ıtionship between the volume elasticity coefficient E_1 and thickness and radius of membrane of the generator is en by

$$E_1 = \frac{16em^2t^3}{\pi(m^2 - 1)r^6} \tag{4}$$

ere e is the modulus of elasticity of the metal of the mbrane, m is the reciprocal of Poisson's ratio, t is the ckness of the membrane and r is the free radius of the cular membrane. This equation was developed from an ıation of Roark⁽⁹⁾ appertaining to the behaviour of cirar metal plates under stress, and the definition of Frank⁽⁸⁾ t in liquid filled manometer systems the volume elasticity fficient E is given by $E = dp/dv$.

To investigate the above postulate an undamped optical nometer system with a known volume elasticity coefficient 1 undamped natural frequency was used as the test instrunt. Because the degree of damping of this system was than 0·05, the undamped natural frequency and the onant frequency were the same.

Four pressure wave generators were constructed; a different dulus of elasticity was obtained by having a membrane of ferent diameter or thickness (see table). Each generator s connected in turn to the test manometer system, after e had been taken to exclude bubbles of air in the combined tem by filling both manometer and generator first with bon dioxide and then with cold boiled distilled water. e resonant frequency of each combined system was then ermined. The size of the generator membrane, the volume sticity coefficient and undamped natural frequency of the ıerator filled with liquid, and the results of the deternations of the resonant frequencies of the combined tems are shown in the table.

Results of tests on one manometer system using four pressure wave generators

Pressure wave generators				*Resonance in combined generator-manometer system*	
Membrane size					
diam. *(cm)*	*thickness* *(in.)*	E_1 *(dyn cm^{-5})*	$f_n(G)$ *(c/s)*	*Calculated* *c/s*	*Measured* *c/s*
3·0	3/1000	$2\cdot7 \times 10^5$	37	186	180
6·5	22/1000	$1\cdot0 \times 10^6$	72	187	179
3·0	22/1000	$1\cdot1 \times 10^8$	750	220	225
2·0	22/1000	$1\cdot2 \times 10^9$	2450	455	435

The test manometer was an optical manometer with a volume sticity coefficient of $2\cdot5 \times 10^8$ dyn cm^{-5} and an undamped tural frequency of 182 c/s. E_1 is the volume elasticity coefficient d $f_n(G)$ the undamped natural frequency of the liquid filled ıerator alone. The values in column 6 were calculated on a sis of the theory put forward in this paper, and those in column 7 re determined experimentally.

It is seen (refer to table) that when the volume elasticity efficient of the generator was small compared with that of manometer, the resonant frequency of the combined stem was equal to the undamped natural frequency of the ınometer system alone. Generators G_1 and G_2 had volume sticity coefficients which were 1/1000 and 1/250 that of the ınometer system under test ($2\cdot5 \times 10^8$ dyn. cm^{-5}); with ese generators coupled to the test manometer the calculated olumn 6, 186 and 187 c/s) and the measured (column 7, 0 and 179 c/s) undamped natural frequencies of the comıed generator manometer systems were similar to that of manometer system alone (182 c/s). But when the volume elasticity coefficient of the generator was of the same order as that of the manometer the resonant frequency of the combined system was much greater than that of the manometer system alone. The table shows that generators G_3 and G_4 had volume elasticity coefficients of one half and 4 times that of the manometer system and in each case the calculated (220 and 455 c/s) and measured (225 and 435 c/s) undamped natural frequencies were much higher than that of the manometer system alone (182 c/s). The table also shows that this latter result was obtained in spite of the fact that the undamped natural frequencies of the two generators G_3 and G_4 when separate (column 5, 750 and 2450 c/s) were much greater than that of the manometer system alone (182 c/s); this finding is contrary to the assumption of Isaacson and Jones.⁽⁷⁾

The results support the theory suggested above; when recording the dynamic constants of a manometer system by attaching a pressure generator the volume elasticity coefficient of the generator must be small compared with that of the manometer system.

Such generators may also be used to obtain the flat response of manometer systems. The generator membrane will respond in a linear manner to increasing driving frequencies provided that the undamped natural frequency of the membrane alone is at least four to five times that of the highest driving frequency (Frank⁽⁸⁾).

EXAMPLE OF THE USE OF THE PRESSURE GENERATOR: EXAMINATION OF A DAMPED CAPACITANCE MANOMETER SYSTEM

A pressure generator was constructed (Table 1, column 1, G_3; modulus of elasticity $1\cdot1 \times 10^8$ dyn. cm^{-5}) with which to test a capacitance manometer (modulus of elasticity $7\cdot1 \times 10^9$ dyn. cm^{-5}) to which a needle 6·1 cm long and 0·02 cm bore was attached. The undamped natural frequency of the membrane of generator G_3 was calculated to be 2520 c/s; thus the membrane alone would respond accurately to driving frequencies in excess of 500 c/s.

The needle of the manometer system was also attached to the generator and an air and watertight junction was obtained by tightening up a screw mechanism which gripped a rubber washer around the needle. The input to the strain gauge, the output from the capacitance manometer and a 50 c/s time trace were displayed on a d.c. oscilloscope and photographed.

The response of the combined capacitance manometer-generator system to an increasing frequency of pressure variation is shown in Fig. 3; the resonant frequency of the

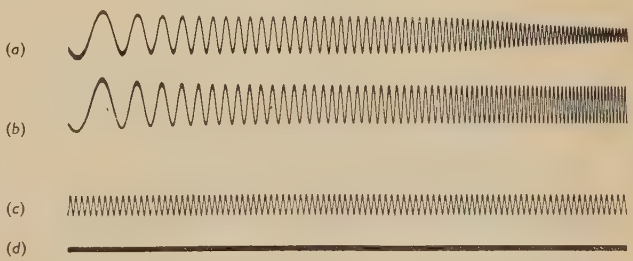

Fig. 3. Response of a slightly underdamped capacitance manometer system to a sine wave pressure oscillation of increasing frequency

(a) output of capacitance manometer; (b) input to pressure generator from oscillator; (c) 1/50 sec time trace; (d) base line.

system was found from a similar record, but one in which the frequency of the pressure variation was increased slowly.

The flat response of the manometer system was determined by increasing the frequency of the generated pressure pulse in steps and recording the response of the manometer system. The relative amplitude at each driving frequency was calculated by first expressing the peak-to-peak amplitude of the pressure record as a fraction of the peak-to-peak amplitude of the oscillator record to compensate for any change in amplitude of the pressure variation resulting from a change in input voltage. This factor was then expressed as a fraction of a similar factor obtained at a driving frequency of 5 c/s; at this frequency the output of the oscillator was considered to be of a true sine wave form. This relative amplitude of the pressure variation was plotted against the driving frequency as shown in Fig. 4.

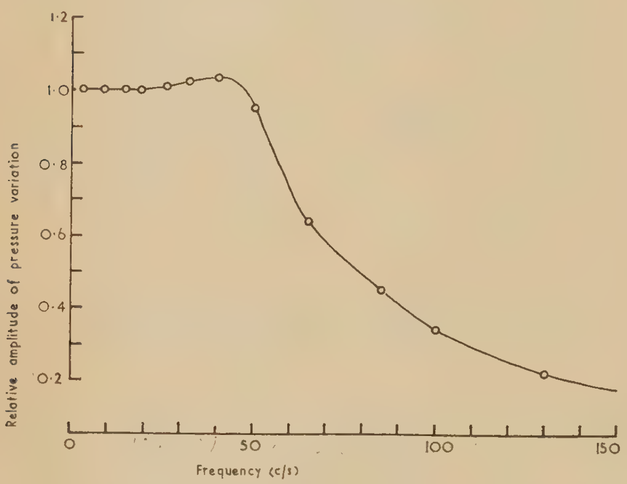

Fig. 4. Relative amplitude of the pressure variation plotted against the frequency. Note the flat response ($\pm 3\%$) out to 50 c/s

The damping in the system was determined from a record such as is shown in Fig. 5. It may be expressed as a ratio, the degree of damping (Hansen⁽²⁾) or as the percentage overshoot (Hansen and Warburg⁽¹²⁾). The undamped natural frequency of the manometer system was calculated from equation

$$f_n = f_R / \sqrt{(1 - 2D^2)}$$

where f_n is the undamped natural frequency, f_R is the resona frequency and D the degree of damping.

The dynamic constants of the capacitance manometer w needle attached were:

Flat response ($\pm 3\%$)	50 c/s
Resonant frequency	43 c/s
Overshoot	9·8%
Degree of damping	0·6
Undamped natural frequency	83 c/s

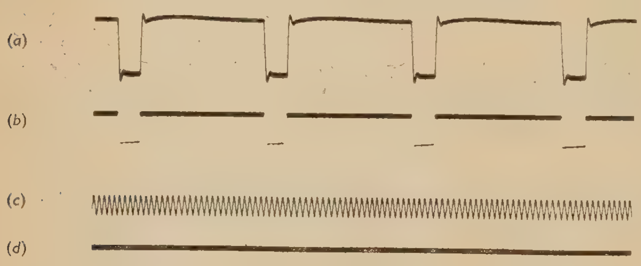

Fig. 5. Response of the capacitance manometer system to square wave pressure changes

(*a*) output from the capacitance manometer; (*b*) square wave input to the strain gauge; (*c*) 1/50 s; (*d*) base line.

Therefore one use of the pressure generator is to determi the dynamic capabilities of a manometer system; these m be expressed in terms of the flat response and/or undamped natural frequency and degree of damping. also the instrument may be used to test a manometer sys immediately prior to physiological experiments. Once dynamic constants of any manometer system have be obtained, it is only necessary to connect the generator to t manometer system and obtain the resonant frequency as re on the dial of the oscillator. If this frequency is the same that recorded in the original investigation of the dynam capabilities, there are no bubbles of air trapped in the syste and its constants are those found in the previous investigat

ACKNOWLEDGEMENTS

I am extremely grateful to Mr. E. S. Stainthorpe Mr. E. Bell for technical assistance.

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Laboratory and workshop notes

)-ring vacuum valve for use with a visible flow industrial glass apparatus

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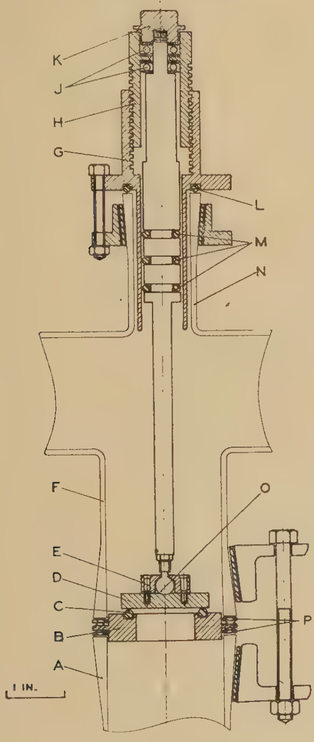
[*Note received* 21 *July*, 1958]

e use of stopcocks of large bore (½ to 1½ in.) in high vacuum tems presents considerable difficulties. In cold weather taps tend to stick. Warming of the stopcock is fraught h danger because of the possibility of leaks developing ough the grease seal. Fine adjustment of the aperture is nost impossible. Gas present in the system tends to be orbed to some extent on the large area of grease which is osed when the aperture is closed.

reckshot and Denny* have described a sliding piston e of glass vacuum valve in which these difficulties have n overcome by the use of rubber O-rings to provide a l, and threaded extensions designed to provide for fine justment of the aperture. The authors have incorporated se features in an improved version of the valve, robustly ilt of stainless steel, designed to withstand atmospheric ssures and to permit fine adjustment of the valve aperture.

The valve, shown diagrammatically in the figure, operates the vertical stem of a 2 in. diameter Quickfit Visible Flow .V.F.) (by Quickfit and Quartz Co. Ltd.) tee piece *F*, to stem and the horizontal arms of which Q.V.F. piping is attached. The tee piece has been modified to take the valve by the addition of a 3 in. length of pipeline *N*, 1 in. diameter, in a central position directly opposite and in line with the stem of the tee.



O-ring vacuum valve

The body *G* of the valve is attached to the 1 in. diameter pipe flange by a modified form of Q.V.F. fitting, in which a projecting metal flange on the body replaces the usual metal backing flange. An O-ring *L* between the flat-ground end of the flange and the body of the valve ensures a vacuum-tight seal. The valve seat *B* is held between the flange of the stem *F* and the flange of the attached piping *A* by the usual Q.V.F. pipe union fittings, being separate from each by a neoprene interface gasket *P*, forming a vacuum-tight seal. An O-ring *C*, set in the valve seat ensures a vacuum-tight seal between the valve *D* and the valve seat. The valve *D* is loosely attached to the spindle by means of a split ring *E* and steel ball *O*. The loose fitting allows the valve to tilt a few degrees from the horizontal plane in all directions so as to accommodate any small misalignment of valve and valve seat which may exist. The ball is attached to the spindle by a screwed length of rod which permits, in conjunction with the use of a locknut, a lengthwise-adjustment of the spindle of up to 1 in. The piston slides in a guide tube on three O-rings *M* which provide a vacuum seal and hold it centrally in the tube. The internal flange on the bonnet *H* together with the flange on the locking nut *K* attached to the end of the piston ensure that movement of the bonnet in or out of the body will cause a corresponding movement of the valve. Threading of body and bonnet enables the size of the valve aperture to be finely adjusted by rotating the bonnet. Ball bearings and washers *J* enable the bonnet to be rotated without rotating the piston.

The authors wish to thank the Chief Scientist, Australian Defence Scientific Service, Department of Supply, Melbourne, Australia, for permission to publish this note.

Vacuum valve indicator light

By D. H. Cooper, Associated Electrical Industries Ltd.,
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[*Note received* 23 *May*, 1958]

When using a vacuum evaporation plant or similar vacuum apparatus it is desirable to have an indication of which valves are open and which closed. With the Saunders-type vacuum valves most commonly used this is not apparent, since the turn-cock has to be rotated a number of times between fully on and fully off, and in many types the spindle itself does not screw in and out.

A simple method of providing the valve with electrical contacts for operating an indicator lamp has been devised and its application to a ¾ in. valve (by Edwards High Vacuum Ltd.) is shown in the diagram. A piece of aluminium foil *A* is stuck to the outer surface of the rubber diaphragm *B* with a rubber adhesive, and insulated from the outer casing of the valve with a piece of cellulose adhesive tape *C*. When the valve is closed the thrust block *D* pushes the rubber diaphragm down over the valve opening, and only when it is tightly shut does this block *D* contact the aluminium foil. Electrical connexions are made to the aluminium foil and the body of the valve. With this minor modification, involving no interference with the vacuum seals, the valve indicator light has worked satisfactorily over a period of months.

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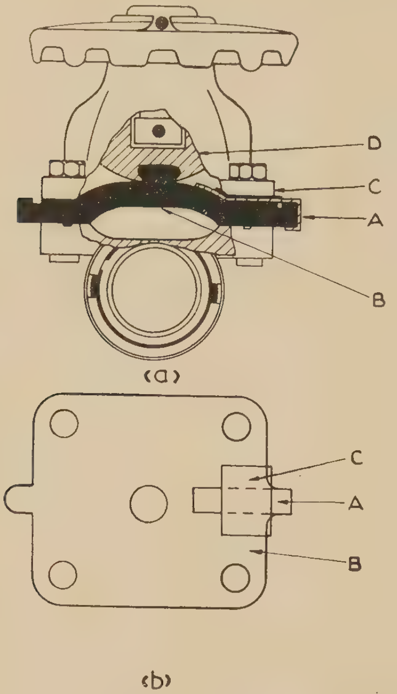
* Preckshot, G. W., and Denny, V. E. *Analyt. Chem.*, **26**, 1398 (1954).



Vacuum valve modified to operate indicator light

(*a*) Detail of valve.
(*b*) Top view of diaphragm.

Liquid-air level controller for cold traps

By K. H. Purser, M.Sc., Department of Nuclear Physics, and J. R. Richards, M.Sc., Ph.D., Department of Radiochemistry, Australian National University, Canberra

[*Note received* 19 *August*, 1958]

A device has been constructed which will maintain an essentially constant level of liquid air in a cold trap for a period of several days. Provided that the trap and the liquid-air reservoir are at about the same level, the operation of the system is independent of any external power source. Visible evidence of operation is provided, together with an advance warning when the liquid-air reservoir requires replenishing. A simple, but effective form of insulation for the delivery tube is described. Figs. 1 and 2 show the main features of the design. When the cold-trap level falls below bulb *B*, evaporation occurs inside the bulb and the reservoir outlet tube is closed by the Neoprene pad V. Natural evaporation then causes a rise of pressure within the reservoir and liquid air is forced into the cold trap.

Valve mechanism. The valve mechanism (see Fig. 2) differs from the principle suggested by Davies and Kronberger,(1) in that the pressure in the reservoir is directly controlled by the bellows *Z* of the gas thermometer.(2) These bellows are enclosed within a brass tube for protection and location. Tubes *K* and *T* limit the travel of the bellows.

The brass thermometer-bulb *B* is connected to the valve bellows by nickel capillary-tubing. All joints in this section are silver soldered. To ensure that condensation would take place within the thermometer, regardless of the composition of the liquid air, oxygen at 2 atm pressure was chosen as t
thermometer filling-gas.

Delivery tube. Good thermal insulation of the delive
tube is essential if large losses of liquid air are to be avoid
Vacuum-jacketed tubes are usually preferred,(3) but the
tubes are difficult to construct and are likely to troubl
some. We have obtained a solution which appears to
satisfactory by using a thermally insulated ¼ in. diamet
stainless-steel delivery tube. The tubing is first polished an
bent to the required shape. After polishing, the tubing i
covered with a single layer of dry asbestos paper. A radiatio
reflector is then formed by a single layer of aluminium f
wound over the asbestos paper. Finally, three or four layer
of asbestos rope are wound over the delivery pipe as furthe
insulation.

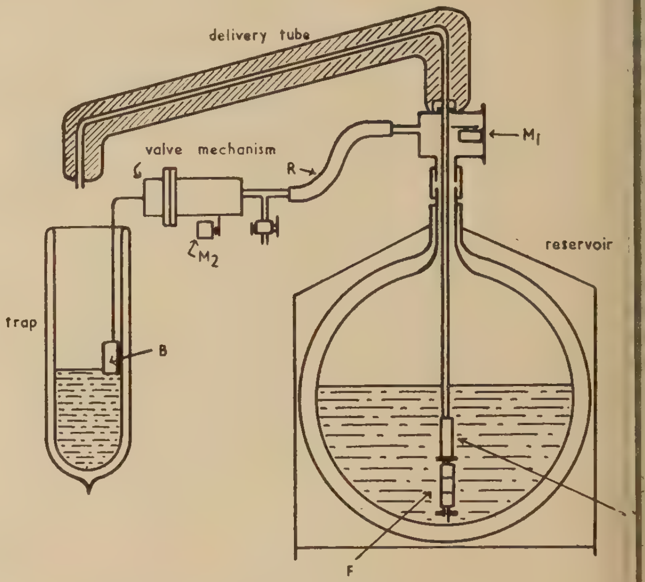


Fig. 1. Level control system

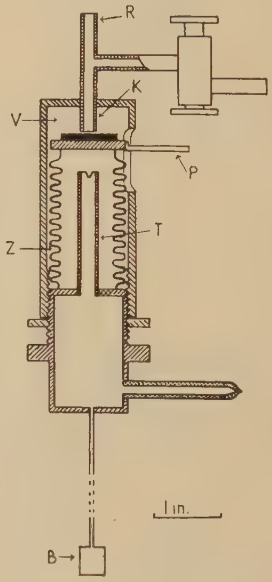


Fig. 2. Valve mechanism

Warning device. One of these controllers operates out o
sight, near noisy pumps. It is desirable to have visibl

dence that the system is operating satisfactorily and vance warning when the liquid-air reservoir needs replacing. e warning system consists of a weighted float which surinds the down-pipe into the liquid-air reservoir (Fig. 1). e weight W is a length of copper tube just heavy enough operate the micro-switch M_1 from which it is suspended linen thread. The cork floats F provide just sufficient oyancy to release the micro-switch, while leaving the ead taut at all times. An indication that the trap is full supplied by a second micro-switch M_2 which is operated a projecting arm P on the metal bellows (see Fig. 2). A essure release valve should be provided. A simple "blow-" by-pass in the reservoir outlet line R suffices.

Performance. A liquid-air controller, built to this design, s been in constant use for over a year and has proved to be iable.

The controller has been used mainly for keeping the level air constant in a mass-spectrometer cold trap. This trap s a volume of about ½ gallon and the makers' specifications e it a life of 16 h. Using the controller, an efficient -gallon liquid-air container lasts approximately 5 days. nder test conditions the liquid-air level fluctuation was proximately 2 mm.

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imple monitor of equipment on a three-phase supply

By T. S. Holden, B.Sc., Division of Building Research,
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(*Note received* 26 *August*, 1958)

connexion with a long term study of the thermal behaviour buildings, various pieces of apparatus were required to erate with minimum attention for a period of several onths. Components included a multipoint potentiometric corder operating continuously, electrical heaters used for a riod of five hours per day, and motor driven draw curtains erated in the morning and evening. Power for this equipent and its automatic control was drawn from a 400 V ree-phase supply. The total current in the neutral lead of is supply was monitored with a clockwork driven recorder, lowing precise analysis of the various faults and failures of e equipment and ensuring that the equipment could be anaged successfully by a simple daily inspection.

An a.c. recording ammeter was connected in the neutral ad by means of a current transformer to give the required nge: 16 A in the present case. This was improved by ssing the neutral lead around the core of a radio type power ansformer with the secondary windings removed, and a 0–400 V a.c. recorder (by Evershed and Vignoles Ltd.) thout its multiplying resistances was connected to the imary of the transformer.

The electrical heating consisted of twelve separate 1000 W eaters, with four connected across each phase of the supply. ith all heaters on, the out-of-balance current was quite nall, although fluctuations of the individual supply voltages of the three phases caused the resulting trace on the recorder to have a fine structure which assisted in determining whether or not the heaters were in operation. Failure of a single heater was readily discernible as a deflexion of about one quarter of the full scale. To detect a power failure in the phase supplying the temperature measuring recorder and the automatic control gear, a 10 μF capacitor was connected across that phase to give a continuous out-of-phase current of 0·8 A, readily discernible on the trace as a small zero shift. Similarly a 20 μF capacitor was connected across the fractional horsepower motor operating the draw curtains, because this motor did not draw sufficient current to indicate its operation clearly.

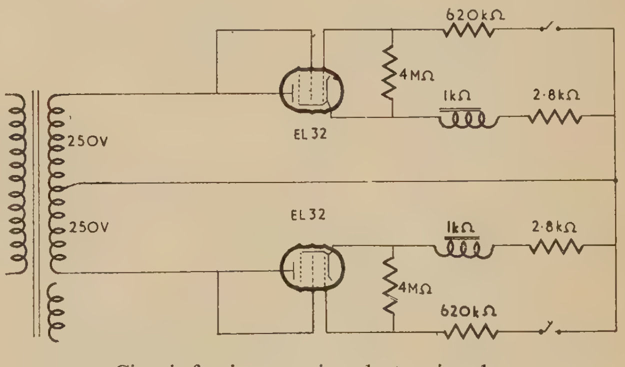
Experience with the system over a period of several months has shown that quite complex faults in the various pieces of apparatus can be analysed precisely, helping considerably in pin-pointing the causes of such faults. Suitable adaptations and modifications for other experimental systems powered by a three-phase supply will suggest themselves.

Inexpensive electronic relay for use with toluene regulators

By M. I. Pope, B.Sc., Ph.D., A.R.I.C., Department of
Chemistry, University of Exeter

[*Note first received* 7 *August, and in final form* 12 *November*, 1958]

In view of the relatively short life of thyratron valves fitted to commercially available thermostat controls and the not unappreciable cost of these units, an attempt has been made to produce a reliable, rapid-acting and cheap electronic relay for use with toluene regulators. For this purpose an ex-Admiralty "Valve Indication Unit" (AP 66150) containing two post office type 3000 double-make relays and two EL 32 valves was purchased; this, together with all the additional components required for conversion, cost rather less than 25*s*. The circuit, which was designed to require a minimum of modification to the existing installation (see Fig.) has proved quite reliable, is capable of rapid switching and causes a current of less than 10 μA to pass through the toluene head. The relay contacts are of the heavy duty variety and a similar unit has been used in this department for switching currents of up to 8 A at 180 V a.c. during the past two years. Some care must be taken in the insulation of the leads to the toluene regulator as input resistances of several megohms have been found to be sufficient to actuate the relay. When only one of the two independent relays is in use it is advisable to short out the input to the second circuit.



Circuit for inexpensive electronic relay

Wave-guides for use in low temperature cryostats

By A. Caistor, S. J. Fray and W. C. Hopper, Royal Radar Establishment, Great Malvern, Worcs.

[*Note first received* 18 *August, and in final form* 25 *September*, 1958]

A major source of heat leak in microwave experiments at low temperatures is the wave-guide, which feeds down through the cryostat head at room temperature to a load or cavity in the refrigerant. Evaporation losses are reduced by using a wave-guide of low thermal conductivity such as glass, plated on the inside, or German silver, and by decreasing the wall thickness to a minimum. At the Royal Radar Establishment during the last four years, many lengths of very satisfactory wave-guide (over 3 ft long) have been made for use at wavelengths of 8·5 mm, 1·25 cm and 3 cm from standard 0·1 to 0·2 mm walled 70/30 cupro-nickel tube of circular cross-section supplied by Messrs. Johnson-Matthey Ltd.

A tube, with an internal circumference slightly less than the internal circumference of the required wave-guide, is selected and annealed at bright cherry-red heat in a vacuum ($10^{-2} - 10^{-3}$ mm of mercury).

A tapered steel mandrel with the same dimensions over the last quarter-inch of its length as the final internal dimensions of the wave-guide, is attached to a four-foot steel rod and pulled into the end of the annealed tube until about one-inch of the tube protrudes. Some shaping of the tube on the mandrel with a hammer is usually necessary to enable the mandrel to be pulled into the tube. This work-hardens the tube and, to shape it successfully, several re-annealings may be required. The tube is then inserted through the head of a lathe so that the shaped end of the tube protrudes from a die which is held in the lathe chuck, and the rod supporting the mandrel is secured on a tubular extension to the lathe head, as shown in the figure. The end of the cupro-nickel guide protruding from the die is plugged and gripped on the lathe carriage which is wound out steadily by hand, drawing the shaped guide with it. Care must be taken to centre the plug accurately on the lathe carriage as a slight misalinement will produce bowing of the wave-guide. Liquid soap lubricant on the mandrel and die greatly assist the drawing.

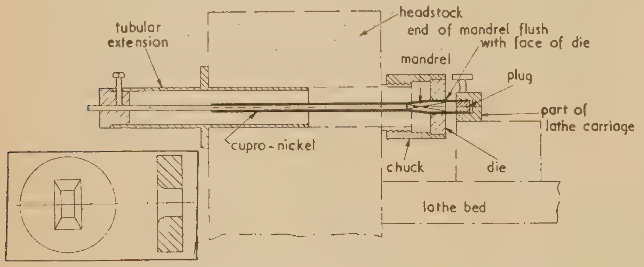


Diagram showing cupro-nickel tube set up in lathe ready for drawing

Inset: Enlarged view of die

The lathe must be large enough to permit the tube to pass through the headstock and have sufficient carriage movement to produce the length of guide required. The forces required for the process can be kept small by drawing the tube through a succession of dies, but annealing is always necessary between each pass. A 10 in. lathe has been used to draw tubing to a rectangular section 0·280 × 0·110 in. in one pass; only one pass was necessary to form wave-guide of section up to 0·510 × 0·255 in. on a 22 in. lathe, but tw passes were required on this lathe to form 0·90 × 0·40 in wave-guide. The accuracy of these lathes as turning machine has not been impaired in any way as a result of using ther as drawbenches, but if smaller lathes were used it would b an advantage to increase the number of passes. If circula section tube of the correct circumference is not available, th nearest size is selected and drawn to the required dimensio by a similar process to that described above, but with circula dies and mandrels.

To reduce the attenuation of the guide the inside is give a light plating of silver. This presented some difficulty a first but the following procedure proved satisfactory. Th guide is degreased in trichlorethylene, boiled in standar cleaning solution (see the table), then rinsed and thoroughl dried. This is followed by five minutes in a bath of con centrated sulphuric acid with 1% of nitric acid. Afte further washing the guide is given a cathodic clean. Fo this a stainless steel wire anode, suitably insulated on spacers is inserted through the centre of the guide and sodiu cyanide is pumped through at approximately 1 gal/h. A current of about 60 mA/cm of guide for a few minutes gives a satisfactory cathodic clean, after which the pump is trans ferred to silver solution consisting of 10 g of silver cyanide and 60 g of sodium cyanide to 1000 ml. of water, and plated for twenty minutes at 30 mA/cm of guide using the same anode. This process gives an adherent uniform deposit o silver of about 0·0001 in.

Composition of cleaning solution

Soda ash	40 g
Caustic soda	13 g
Trisodium phosphate	13 g
Sodium cyanide	13 g
Sodium silicate	6·25 g
Water	1000 ml.

Some tubes have been plated first and then drawn int guides without damaging the silver surface. Twists and bends can be made very easily if the guides are reannealed at dull red heat and then packed with a low melting point alloy according to standard practice. The attenuation of a guide for use at 36 000 Mc/s was found to be 0·25 dB/ft if silver plated, and 0·94 dB/ft unplated.

By a similar tube-drawing process vacuum tight concentric cables can be made. A standard cable with the outer covering and braiding removed is threaded through a close-fitting annealed cupro-nickel tube. The tube is then drawn down, making a tight fit on the cable, by pulling through a circular die.

Acknowledgement is made to the Controller of H.M. Stationery Office for permission to publish this note.

Orientation control for germanium wafers

By B. J. Coughlin, B.Sc., G. L. Davis, B.Sc., Ph.D., A.R.I.C., F.I.M., and R. L. Kingsnorth, B.Sc., The Mullard Radio Valve Co., Mitcham Junction, Surrey

[*Note received* 12 *August*, 1958]

In the manufacture of semi-conducting devices employing wafers of germanium single crystals, it is usually important that the orientation of the wafers should be controlled to within a degree or so. In most cases the surface of the wafer should coincide as nearly as possible with a (111) plane—

ally that normal to the [111] direction of growth of the ot; this note describes a method for accurately mounting ots for cutting slices and a method for determining the entation of small wafers.

ngots are grown from seeds of precisely known orienta- ns but, owing to such factors as irregular ingot shape, alinement of the seed, etc., difficulties are often en- untered in sawing the ingot to give slices correctly oriented. wever, germanium readily cleaves on the (111) plane, and he ingot is given a small notch by a diamond glass cutter with a saw-cut, tapping or levering with a screwdriver will iate fracture to reveal a surface roughly planar consisting a number of stepped (111) faces of the required family, ned by short planes from other families. The main faces n now serve as a mirror for an optical beam method for ting up the crystal on the cutting jig, using the following cedure.

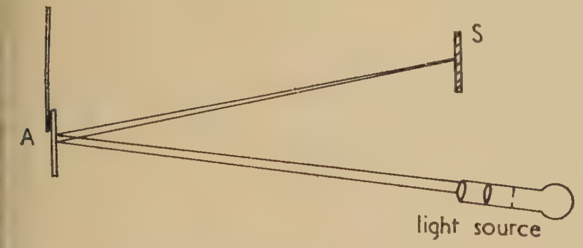


Fig. 1. Schematic diagram of ingot cutting apparatus

With the apparatus drawn schematically in Fig. 1, a rror is placed against the sawing wheel at *A* and the lected beam is focused and serves to give a reference sition on the screen *S* indicating the cutting plane. The eel is now retracted and the ingot is placed approximately place at *A* and adjusted until the bright spot coincides with original reference. Variation in the optical path due to stepped ingot face degrades the image somewhat, but a cision of better than $\frac{1}{2}°$ is easily attained with one metre tical path. Reflexions from other planes fall too far from screen to interfere.

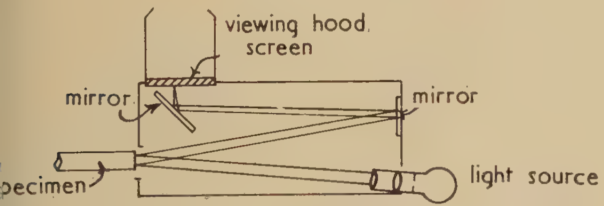


Fig. 2. Ingot cutting apparatus with optical beam folded

It is more convenient for sawing to fold the optical beam ther as in Fig. 2, so that the device is more compact and screen is near to the ingot to assist adjusting. This cedure has also been applied successfully to silicon ingots ng reflexions from cleavage planes and etch-pit faces.

The method of using natural (111) planes as mirrors can extended for the examination of germanium wafers cut m single crystals. An indium pellet is melted on a wafer face and the temperature raised so that appreciable ution of the germanium takes place. On cooling, the rystallized germanium mostly takes the form of platelets wing into the indium and essentially continuous with the ginal crystal (Fig. 3).

If the indium is now removed (e.g. by dissolution in hydrochloric acid) the platelets are revealed with specular surfaces which can be used for orientation measurement. In this case the optical axis of Fig. 1 is near vertical so that the wafers can lie on a reflecting reference plane which serves to locate a central spot on the screen. The screen is calibrated with concentric circles representing departures from orientation by given intervals from this centre [referring to the true (111) plane]. From the platelets is reflected a second light spot on the screen, and a precision of 0·2° in the orientation is easily achieved with an apparatus of convenient dimensions. Good agreement has been obtained with X-ray methods.

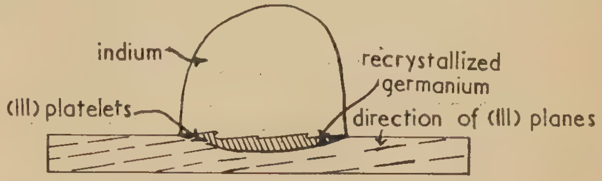


Fig. 3. Section of treated wafer

The authors wish to thank Dr. J. A. M. van Moll, Head of the Material Research Laboratory and the Directors of The Mullard Radio Valve Co. Ltd., for permission to publish this note.

Improved machine for lapping very thin slices of semiconductor material

By D. Baker, B.Sc., Post Office Research Station, Dollis Hill, London, N.W.2

[*Note first received* 24 *September, and in final form* 23 *October*, 1958]

The fabrication of semiconductor devices of uniform characteristics and small base width requires slices whose thickness is both uniform and reproducible to a high degree of accuracy. Existing types of lapping machines have proved unsuitable for semiconductor materials owing to wafer damage or to the production of non-parallel surfaces. Machines which lap only one side of a slice at a time are not suitable for very thin slices since difficulty is usually experienced in preventing abrasive from working between the slice and the work holder thus tilting the slice and producing non-parallel surfaces. Lapping machines of the drill press type in which the slices are driven eccentrically between two ring type lapping plates have been shown to be capable of producing surfaces parallel to the required accuracy but excessive slice damage occurs. During lapping the force required to move a slice between the laps against frictional forces is applied *via* the mask or work holder at one edge of the slice and any movement of the mask in the direction perpendicular to the lapping surfaces will tend to bend the slice, so much so that for germanium and silicon the bending moment is large enough to cause fracture.

An improved form of lapping machine has been developed in which the forces acting upon the slice edges *via* the mask are very small—thereby minimizing edge damage—since they are the difference between the nearly equal frictional forces acting upon the upper and lower surfaces of the slice instead of the sum of the frictional forces in the case of the drill press lap. An eccentric motion is applied to the upper lap and slices are placed in a circular mask which is free to move under the influence of frictional forces. The mask should traverse the same distance relative to the upper and lower laps and the required motion is achieved by the use of a retaining wall around the edge of the lower lap and a raised rim around the circumference of the mask together with suitably chosen lap and mask diameters. The arrangement is shown in Fig. 1. If, for an upper lap of diameter D_1, and a lower lap of larger diameter D_2, the diameter of the mask is $(D_1 + D_2)/2$ and the eccentric throw is $(D_2 - D_1)/2$ then the slices are moved through a circle of diameter $(D_2 - D_1)/4$ relative to both the upper and lower laps.

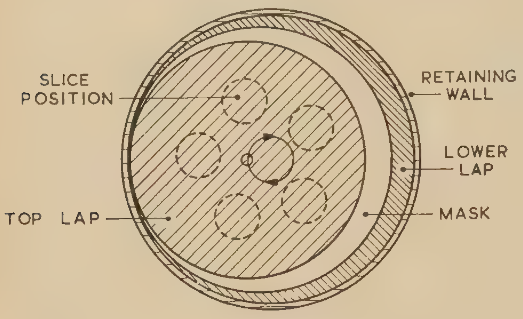


Fig. 1. The improved lapping machine

The general arrangement of the lapping machine is shown in Fig. 2. The machine consists of two surface ground circular plates of stainless steel, the lower plate of diameter 6 in. being pinned to a cast iron base, the upper plate of diameter 5 in. being driven by an eccentric pin rotating at 30 to 120 rev/min. The eccentric throw, nominally 0·5 in., is adjusted to allow a small working clearance between the upper lap and the retaining wall and may be increased to 1·0 in. for truing the laps after prolonged use. The driving pin is a free fit in a replaceable phosphor–bronze bush inserted centrally in the upper lap, and applies no vertical pressure to the lap, the pressure applied to the work being provided entirely by the weight of the upper lap which may be increased from 1·5 to 4·5 lb by additional brass rings.

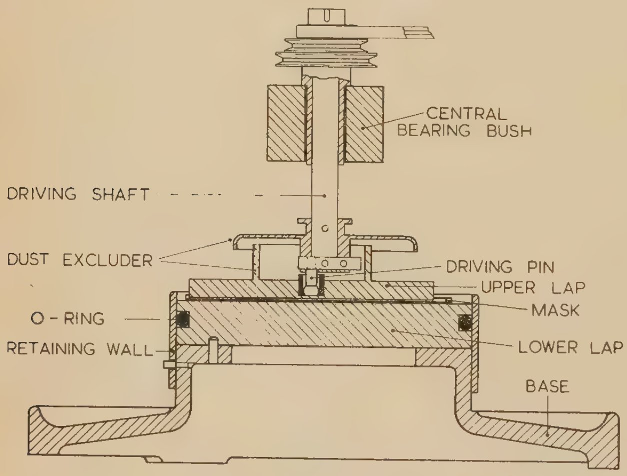


Fig. 2. Simplified section of the lapping machine

A circular mask or work holder of thickness equal to that of the slices required lies between the two laps. The mask may be made from thin metal foil or hard plastic. A ma of cellulose acetate 5·5 in. in diameter with a raised r 0·1 in. high may be obtained by clamping a sheet of cellul acetate between two metal disks and then rolling the edge this assembly over a hot plate maintained at a temperatu of about 120° C. Five or more equally spaced holes, t diameter *d* of which should be just large enough to all the slices to rotate, are cut at a radial distance 2·125 — *d*/2 in. thus ensuring that the slices being lapp are not carried outside the upper lap.

The travel of the mask is restricted by a retaining wall, t height of which may be adjusted to one of three position (1) Fully raised to allow complete immersion of mask a work in the abrasive suspension. (2) Normal position wi the slots cut at the top of the wall level with the lap surfa allowing the dispersal of surplus abrasive. (3) Fully lowere thus enabling the upper lap, mask and work to slide off t lower lap at the completion of lapping. An O-ring of sy thetic rubber is used to seal the join between the wall and t lower lap.

The final thickness of the lapped slices is approximat equal to that of the mask since the mask is manufactur from a resilient material which, compared with germaniu and silicon, is highly resistant to abrasion and masks cellulose acetate may be used for several hundred hou before replacement is necessary. The variation in thickne of a batch of slices after lapping will be dependent upon t variation in thickness of the mask itself. It is therefo essential that the mask should be made from selected she whose thickness is within the required tolerance over t whole area of the mask.

The abrasive used for lapping very thin slices of se conductor material is 303 silicon carbide, the average partic size of which is 15 μ, applied to the lap as a suspension kerosene prior to lapping. The machine may then be r for several hours without additional abrasive since a surpl of abrasive is maintained between the mask and the lap The rate of lapping, for a given abrasive size and sem conductor, is directly proportional both to the speed rotation and to the weight of the upper lap and inverse proportional to the area of the slices. The lapping rate germanium is 0·010 in./h for 5 slices each 1 in.^{2} in area usin an upper lap weighing 4·5 lb and a speed of 120 rev/mi with 303 silicon carbide abrasive. A uniform fine grou surface with no detectable edge damage is obtained und these conditions. The lapping rate may be increased b using larger abrasive, but the depth of damage estimated b a method described elsewhere(1) is thereby increased. Th lapping rate of silicon is approximately half that quoted fo germanium. Since slice breakage is most likely to occur the commencement of lapping, when the upper lap is sup ported in general by three points, it is advisable to commenc lapping with the minimum load and speed of revolution fo several minutes, after which the lapping rate may be increase

Batches of 5 or more slices per batch which have bee lapped from an initial thickness of 0·017 in. to a fin thickness of 0·010 in. by the above method show a max mum variation in thickness over all slices in the batch ±0·000 04 in. even to within 0·010 in. of the edges of th slices. Germanium slices have been lapped down to a fin thickness of 0·004 in. without breakage occurring.

The author wishes to acknowledge the helpful advice give by Mr. R. Jones on lapping techniques and the assistanc of Mr. R. J. Jury and Mr. L. J. Wright in the mechanica design.

Acknowledgement is also made to the Engineer-in-Chief

e General Post Office for permission to make use of the ormation contained in this paper.

REFERENCE

Baker, D., and Yemm, H. *Brit. J. Appl. Phys.*, **8**, p. 302 (1957).

Simple light source of about 10 mμs duration

By G. Porter, M.A., Ph.D., and E. R. Wooding, Ph.D., A.Inst.P., University of Sheffield

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source is illustrated in Fig. 1 which produces pulses of ;ht having a duration of about 10 mμs. It consists of cm of 71 Ω coaxial cable (type 3026 by British Insulated allenders Cables Ltd.), the spark occurring between the ner conductor of the cable and a brass plate having a ntral hole of the same diameter (0·14 cm) as the conductor. ne brass plate, 0·012 cm thick, is soldered to the shell of coaxial plug (type 166 by Aerialite) and the electrode paration for the shortest duration is found to be about 05 cm. The spark occurs to one side of the inner electrode nce there are irregularities in the surfaces and in the geometry the electrodes. The spark gap is not matched to the cable ectrically, but the distant end of the cable is terminated a 10 MΩ resistor and is effectively an open end.

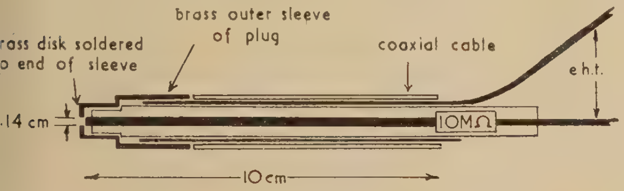

Fig. 1. Diagram of spark source

The duration of the current pulse was calculated from the mensions of this cable and was 1 mμs. The amplitude the pulse was taken to be equal to the ratio of charge to uration and was 7 A when the cable was initially at a otential difference of 1 kV. The stored energy was then μJ resulting in a mean spark power of the order of 1 kW.

The duration of the spark was recorded by means of an .C.A. type 931A photomultiplier with a 100 Ω load, the sulting signal being fed into a Tektronix oscilloscope pe 545 *via* a type P405 passive probe and a type 53/54 k e-amplifier.

The duration of the radiation pulse was comparable with e rise time of the oscilloscope and could not be determined rectly. Instead it was estimated from a relationship due Elmore and Sands.(1,2) The rise time t_r of an instrument, e n stages of which have rise times of $t_1, t_2 \ldots t_n$, is:

$$t_r = \left(\sum_{i=1}^{n} t_i^2\right)^{\frac{1}{2}}$$

It was assumed that the rise time of the oscilloscope nd probe) was equal to the decay time, which was deterined by discharging a short length of coaxial cable, and as found to be 13 mμs. The response of the photomultiplier was approximately Gaussian with an r.m.s. value of 1·5 mμs(3) and it was calculated that the rise time was 2·5 mμs. The load resistor of the photomultiplier and the associated capacitance had a rise time of 5 mμs. These values were inserted in the above expression and the overall rise time of the recording instruments was calculated to be 14 mμs.

The signal recorded on the oscilloscope (Fig. 2) had a rise time of 14·0 ± 0·6 mμs and a decay time of 18·2 ± 0·7 mμs, where the tolerances are the errors of measurement. Hence the radiation pulse must have a rise time of less than 4 mμs and a decay time of between 11 and 13 mμs.

The peak intensity was estimated from the oscillogram by measuring the solid angle subtended by the photomultiplier and integrating over 4 π neglecting the assymmetry of the source and attenuation by the instruments. The peak intensity was of the order of 1 W and the radiated energy had a spectral range greater than 1900 to 6000 Å, the strongest feature being the second positive system of the nitrogen molecule. The mean efficiency of the spark was of the order of 0·1%.

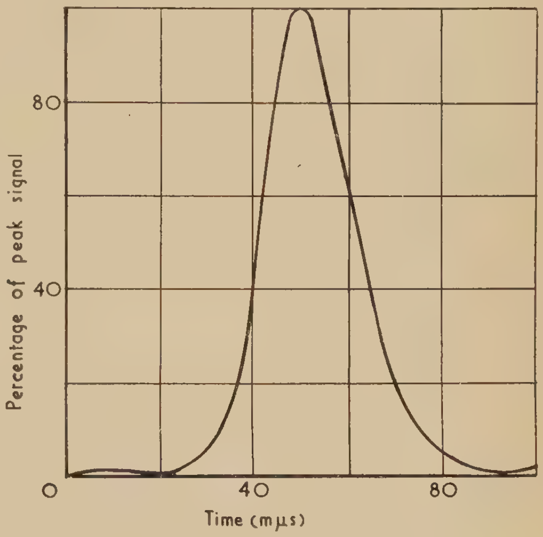

Fig. 2. Signal recorded on oscilloscope

When the source was allowed to run freely at a supply potential of 2 kV, the gap broke down at irregular intervals with an average repetition rate of 10^5 sparks per second. Both repetition rate and amount of jitter depended on the electrode separation and supply voltage.

Malmberg(4) has described a flash tube having a duration of 1 mμs and intensity about one-hundredth that of the source described here.

We are indebted to the General Electric Research Laboratory of Schenectady, U.S.A., for their support of this work.

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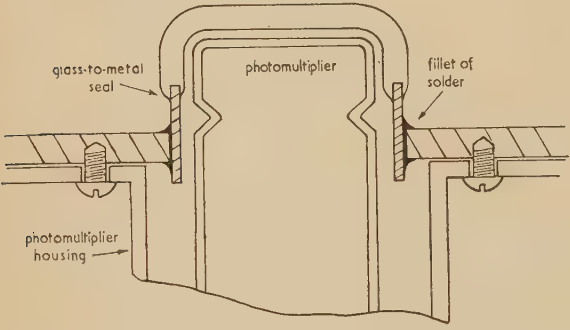
Photomultiplier window for a liquid scintillator

By R. M. Tennent, Ph.D., A.Inst.P., University of Leeds

[*Note received* 31 *July*, 1958]

When liquid scintillator detectors are used, it is of great convenience to view the liquid by photomultipliers through liquid-tight windows. Then, if it is necessary to change a photomultiplier, this can be done without disturbing the liquid. In the past* the author has used flat glass windows cemented, with Araldite D cured at 60° C, into a recess in a stainless steel scintillator tank. Such windows have proved satisfactory for scintillators employing toluene as the solvent, but have leaked rapidly with benzene or mixtures containing methyl alcohol.

Recently, more permanent windows have been made for use with 2 in. photomultipliers as follows. The glass of a 2¼ in. cylindrical glass-to-metal seal (Jencons Scientific Ltd.) was cut about ¾ in. from the seal and a flat glass plate sealed on to the end. The metal (Kovar) was then soft-soldered directly to the stainless steel of the scintillator tank using type PLF 73/16 solder (by Perdeck Solder Co.). The photomultiplier housing could then be bolted to the tank using blind holes as shown in the diagram. Such a window is resistant to the organic liquids commonly used for scintillator solvents. To avoid any possibility of poisoning the scintillator, the exposed portion of the Kovar tube and the solder joint have been painted with a mixture of titanium oxide and water glass.



A photomultiplier window for use with liquid scintillators

Windows made in this way cause the photomultiplier to project into the scintillator. For small scintillator tanks this might be awkward, but with large scintillator tanks it is an advantage to have the photocathode of the photomultiplier well within the tank so that it can "see" all portions of the scintillator.

I am greatly indebted to Mr. K. Fletcher for his skilful glass-blowing and to Mr. W. Cull and Mr. G. F. Charlston for their care in fitting and soldering the window into the tank.

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* Hillas, A. M., Gilboy, W. B., and Tennent, R. M. *Phil. Mag.*, **26**, p. 109 (1958).

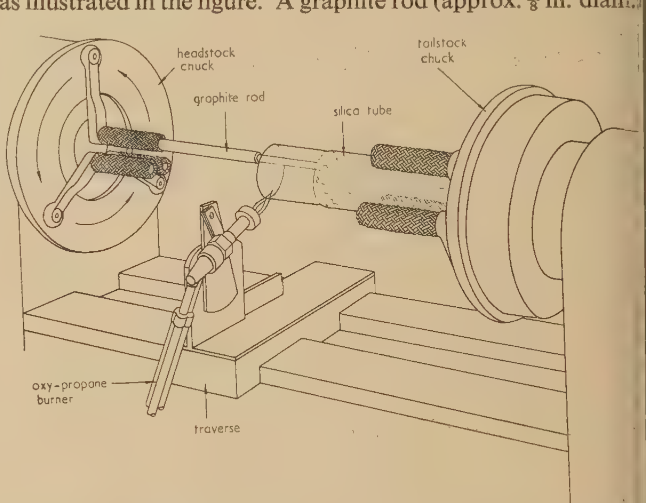
Precision ends for fused silica tubes

By J. Conaboy, Royal Radar Establishment, Malvern, Worcs.

[*Note received* 14 *October*, 1958]

Silica tubes tend to have irregularities in thickness and shap and this is inconvenient when, for example, an "O"-ring sea is required at the end of the tube. It has been possible t form "precision" ends on silica tubes very suitable for a O-ring seal, using an ordinary glass-blower's lathe. As typical example, the diameter of a 3 in. silica tube can b made accurate to ±0·005 in. It may also be possible t fabricate cones and other shapes at the ends of silica tube by this method.

A silica tube of larger diameter than required is centred a accurately as possible in the tailstock chuck of a glass lath as illustrated in the figure. A graphite rod (approx. ⅞ in. diam.) is fitted firmly in one of the steel fingers of the headstock chuck and this chuck is adjusted until the graphite rod describes the required diameter inside the silica tube. The drive is arranged such that only the headstock chuck is driven mechanically, the tailstock chuck being turned by hand. An oxygen–propane burner, usually supported on the traverse, plays a powerful flame on the tube.



Centring of silica tube on the tailstock chuck of a glass lathe

Unlike glass only a small portion of the silica tube can be softened at a time, and as it softens the silica falls on to the rotating graphite rod. Another part of the silica tube is brought into the flame by turning the tailstock chuck by hand. When the whole circumference of a particular section of the tube has been softened and shrunk, the traverse is moved so that the burner is focused on another section. Repeated working of the silica in this way removes large irregularities in wall thickness and diameter.

For greatest accuracy, it is advisable to start with a silica tube having a diameter some 6 mm greater than required. This tube may then be shrunk to the required diameter in a series of decreasing steps. The final step should use a new graphite rod, as the graphite does tend to burn away. The edge of the finished tube is usually uneven and must be ground to the required flatness.

New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

icrofilm and microfiche reader. Micro Methods Ltd., East Ardsley, Wakefield, Yorkshire.

ie V.C. lexicon reader will accommodate microfiche up to maximum size of 9 cm wide and can be fitted with a film rrier to take 100 ft of full-size 35 mm unperforated microm. It is a compact machine which takes up, when not in e, a volume of only 15 × 10 × 11 in. In order to secure e advantage of complete portability, the weight has been pt down to 25 lb. The film carrier for microfilm scanning n be removed and re-fitted very quickly and easily, which cilitates film threading. Transport of the film across the te is effected by a handle mounted on the carrier, and the nage remains in focus whether the film is moving or not. tensioning arrangement eliminates the need for pressure ates and thus prevents accidental scratching.

The fiche image is projected on to a white opaque screen 1 the desk and is approximately 15 in. square. A prism tachment is available which enables the image to be procted on to the screen at any desired reading angle. Magnication is 16, with a gate size of 2·4 × 2·4 cm. The equipent can be set for use with a wide range of a.c. voltages and in be converted to d.c.

ptical digitizer. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

he optical digitizer is a coded commutator using the passage light and photocells instead of electrical contacts and is aimed to have the following three major advantages over echanical digitizers: (1) a lower torque because there are o contacts dragging on the disk; (2) a longer life because echanical wear is limited to the ball bearings; and (3) an ppreciably smaller diameter, resolution for resolution.

An optical digitizer has four main components: an illumating system, a slit disk, a coded disk with a pattern of paque and transparent marks on it, and the photocell etectors. The illuminating system contains a single coldthode flash tube. When the lamp is pulsed, the light asses through the slit disk and the transparent segments of ie coded disk on to the photocells, in which it causes a duction of resistance and a pulse of current to flow. Cells pposite opaque segments are shielded from the light and main quiescent. Each cell is associated with an individual utput line connected either direct to a decoder or to a ore where it can await subsequent manipulation. Standard ecoders and stores at present made by this firm are of the lay type, and amplification is therefore needed to provide dequate power to operate the standard P.O. type 3000 lays. If electronic decoders or stores are being used, mplification may not be necessary.

ubricants. British Industries Products, Selwyn House, London, W.C.1.

everal kinds of oils with special properties have been prouced by the firm. The properties are designed to fit the ecial purposes for which they are required.

The first type is suitable for all delicate instruments, and watches and clocks. It is stated that it remains in globular form and does not spread. It is further said to lose as little as 1% or less in a week by evaporation. A second type, a blend of di-ethyl hexyl sebacate incorporating an approved oxidation inhibitor, works at a temperature of −54·4° C to +51·7° C, and is useful for sensitive instruments working at low temperatures. A third is a dry lubricant composed of colloidal graphite in a volatile carrier. It is claimed that clearances in the mechanism are unaffected by it. The film is conducting, and sometimes this is an advantage, as, for instance, in preventing charges building up on rubber belts.

A further series of lubricants is based on molybdenum disulphide. The basis for the lubricity of molybdenum disulphide lies in its unique molecular structure. Each lamina of the material is composed of a layer of molybdenum atoms with a layer of sulphur atoms on each side. One of these laminae adheres strongly to metal surfaces because of the strong metal-to-sulphur bond. The other laminae slip easily because of the weakness of the sulphur-to-sulphur bond. This, in part, accounts for the tenacity of these lubricants and their low friction coefficient at very high bearing pressures. They are suitable for preventing metal to metal contact and tenacious lubricating films are formed with very high bearing capacities (up to 400 000 lb/in.^{2}). Literature is available giving full details of the various forms and packs of these lubricants with MoS_2 content.

Soldering by painting and heating. Perdeck Solder Products Ltd., Abbey Mills, Waltham Abbey, Essex.

A solder paint has been developed for tinning and soldering stainless steel which is said not to need any separate flux or acid pre-treatment of the metal, and does not itself contain free acid. It is simply painted on the surfaces, heated by any convenient means and, in the case of tinning, residues are wiped off whilst the work is hot. In soldering work, the joint effected is cooled when residual impurities are readily removed by rinsing. Other types of solder paint also manufactured by this firm perform similarly on copper, brass, mild steel, nickel and many forms of cast iron. Research is still proceeding towards developing a similar process for aluminium. The proportion of tin and lead of the solder contained in these preparations may be varied through the full range of British Standards specifications for soft solders including pure tin where lead-free work is essential. According to the tin/lead specification, melting points range between 183° C and 260° C. It is claimed that soft soldered joints of over 17 tons/in.^{2} have been effected using special solder pastes also manufactured by this firm.

Film printer. Fairey Air Surveys Ltd., 24 Bruton Street, London, W.1.

This printer is designed for 35 mm or 70 mm negative film. It is easily portable and is intended for printing positive films from negatives; and also duplicate negatives by using positive stock. It is stated that adapting the machine for either size of film takes only a few moments while the appropriate printing drum is fitted to a centre shaft and guide plates on the feed side are adjusted to the required width. It is claimed that the machine prints lengths of up to 100 ft maximum of film at a constant speed of 9 ft/min and the exposure is adjusted by varying the intensity of the printing lamp.

A viewer is provided between the negative feed spool and the printing drum so that the negative may be viewed continuously just prior to printing and the exposure varied if necessary to compensate for changes in negative density, without stopping the machine. The viewing light is an orange safelight so that the machine may be operated in a darkroom with other photographic equipment. A tunnel from the lamphouse to the printing drum prevents light spill outside the machine. The feed spools are on the left-hand side of the machine and the take-up spools on the right, the upper spools being the negative to be printed and the lower spools the positive material. From the feed spool the negative passes through the viewer and then meets the positive material, after which both are threaded round a polished roller and fed on to the printing drum. On passing round the drum good contact is ensured and at the top of the drum the printing exposure takes place. After exposure the negative and positive are separated once again and rewound on separate spools. The printing drum is driven at a constant speed and both take-up spools are power driven but at a faster rate with slipping belts to ensure a continuous steady take-up from the printing drum. Over feeding from the feed spools is prevented by friction disks on the feed spindles. Exposure is made by a 30 W pearl tubular lamp which is fitted in a well ventilated but light baffled lamphouse. A tunnel from the lamphouse has a $\frac{3}{8}$ in. exposing aperture close to the top of the printing drum. The weight of the complete instrument is 25 lb, and the overall size 17 × 16 × 7 in.

Miniature electric motor. Vactric (Control Equipment Ltd.), Vactric House, Sloane Street, London, S.W.1.

This electric motor has a centrifugally operated governor and externally mounted power transistor which controls the motor armature current. The advantage of this arrangement is the small current which passes through the governor contracts, the bulk of the armature current being switched by the transistor.

It is claimed to have a long and trouble-free life for operation in the temperature range 0°–70° C, and will withstand a wide range of vibration conditions in any plane. The motor can be supplied with a plain or pinion shaft, and can be adapted to take high precision reduction gearheads which are available with ratios up to 360 000 : 1. The motor can be adjusted while running to any desired speed between 3 000–6 000 rev/min. The normal rotation is anti-clockwise when viewed from the drive shaft, but a clockwise rotation can be arranged with a simple circuit modification.

The instrument is mounted by using four holes in the body near the front which are tapped 6 B.A. and are 3/16 in. deep. The following performance details are claimed: output 0–12 W, torque 0–240 g cm, governed speed, pre-set between 3000–6000 rev/min, voltage 28 V, current 0·2–1·1 A, rating continuous, and weight 160 g.

Automatic X-ray fluorescent spectrometer. The Solartron Electronic Group Ltd., Thames Ditton, Surrey.

The X-ray fluorescent spectrometer type XZ736 is intended for the non-destructive testing of materials. It identifies the various elements present by means of their X-ray fluoresce spectra. An X-ray tube operating in the 60 kV region produces a beam of hard X-rays, which are directed on to th sample under test. These X-rays excite the various elemen in the test sample and cause them to emit their characterist spectra. The fluorescent X-rays are collimated and directe on to a crystal, from which they are reflected to a Geige counter. The crystal and detector move simultaneously, th crystal moving through half the angle of the detector, an both stop for a definite time at each of the programme Bragg angles. The instrument can be operated to give continuous scan of Bragg angles, thus producing a graphic record showing qualitatively and quantitatively which elements are present. Alternatively, programmed counting ca be used. Up to twenty-four elements can be examine automatically, the quantity of each element present bein printed out on paper. The position of the crystal an counter at each Bragg angle is controlled to within ½ Instead of taking a count in a fixed position for each elemen it is possible to scan a small range, say ½°, at each positio The equipment can also be arranged to take a continuou analysis of a given element in a compound, alloy, solution o slurry, and to provide a correction or alarm signal if th quantity of this element varies outside specified limits.

To eliminate error due to fluctuation of X-ray output, twin spectrometer is used. The output from the X-ray tu is arranged to impinge on a standard sample as well as o the test sample. The fluorescent X-rays from each sampl are passed through two identical spectrometer channe The rate of counting from the standard sample is then use to control the time of counting from the test sample. T makers claim that under favourable conditions 1 part in 10 of an element can be detected. The counting time for a element depends on the quantity present and varies fro ten seconds to several minutes. In addition, about fiv seconds are required for each positioning of the crystal an counter.

Comprehensive voltmeter. Marconi Instruments Ltd., St Albans, Herts.

This voltmeter, type TF1041B, measures a wide range of d.c and a.c. potentials, and resistances. The advantage ove previous comprehensive voltmeters is that it has an a.c frequency range extended to 1500 Mc/s. It is claimed t have a high all-round performance and a good operationa convenience.

The a.c. measurement range is 25 mV to 300 V, 20 c/s t 1500 Mc/s. The instrument measures d.c. voltages fro 10 mV to 1000 V, and resistance from 0·02 Ω to 500 MΩ. Multipliers can be supplied for up to 2 kV a.c. and 20 kV d.c Both a.c. and d.c. inputs are isolated from the chassis. O all d.c. ranges, a centre-zero facility is available to aid the precise determination of null point in bridges or discriminators

D.C. volts and ohms measurement is simplified by the special dual-purpose d.c. probe with its finger-tip *V*/Ω selector; set to *V*, an isolating resistor is introduced to shield the circuit under test from the effects of probe-lead capacitance. The d.c. supply for ohms measurement is obtained without the use of batteries.

The probe unit used for a.c. measurements houses a disk-seal diode rectifier of the most advanced type. This diode, with its resonant frequency of 3000 Mc/s and low inter-electrode capacitance, with the special design of the probe, makes possible a frequency response which is said to be flat to within 1 dB up to 1000 Mc/s and shows a rise of less than at 1500 Mc/s. Small and cylindrical, the probe weighs 1½ oz, a factor that makes for ease of handling.

ne d.c. section of the voltmeter is essentially a two-stage edance convertor. Each stage embodies two cathode owers and there is heavy degeneration between the input its and the moving coil-meter across the output; this ires that the accuracy is virtually independent of valve acteristics. The filament supply to all valves is stabilized, the effects of meter temperature coefficient are offset series thermistor. The stability and freedom from drift lting from these arrangements are seen by the user as a dy zero, which needs only one setting to suit all ranges. re is no conventional chassis, all components being inted on the rear of the hinged front panel.

er-baths in stainless steel. A Gallenkamp and Co. Ltd., Sun Street, London, E.C.2.

er baths are now being constructed of smooth finish lless steel whose advantages are said to be resistance to osion, ease of cleaning, hard wearing and smart appear- . Two general purpose baths and the bath for Soxhlet actions have already been modified, but retain their inal dimensions and features.

eating is by tubular immersion elements and each bath quipped with a safety head to protect the element should water be allowed to evaporate. Temperature control the Soxhlet bath is obtained by a 3-heat switch for a.c. d.c. supplies or an energy regulator in the model for a.c.

he general purpose baths have six or twelve holes, 1. diameter in the top cover, each hole being fitted with a of stainless steel rings. An energy regulator is available use on a.c. supplies. The Soxhlet bath is suitable for six mblies of glassware, takes flasks up to 500 ml capacity condensers are held by spring clips fitted to an adjustable zontal rod carried by two vertical 24 in. long duralumin

o unit. Servo Units Ltd., Farnborough Road, Farnborough, Hants.

ruments for the rapid and controlled production of a ue of given magnitude and period are produced by this . Three models have been produced and in the latest one, power transistors have replaced the vibrating relay in providing high torque without overshoot. In the new series the motor is fed *via* the power transistors controlled either from a d.c. transistor amplifier or a thermionic amplifier supplied from a transistor h.t. supply all fed from the original d.c. supply. Mains a.c. supply units are also available.

The size of the smallest of these servo units is 3·0 × 2·2 × × 2·25 in. and it has a stalled torque of 1·0 lb-ft with a rate of response of 35°/s, a repeatability of ±0·3% full scale on light load, and on 90% full torque, 2·5%.

A 12 V type is of size 4·10 × 2·55 × 2·50 in., with stalled torque 5·0 lb-ft rate of response 50°/s, repeatability ±0·3% and under 90% full load 2·0%: 360° rotation can also be provided.

The units are available with various gear ratios giving up to twenty times the above speed of response with proportionately less torque. Gears are also available separately for experimental work in conjunction with a standard unit. The gear box unit is also available separately.

The replacement of the vibrating relay by power transistors makes these units considerably more attractive for industrial applications and for fields where minimum servicing is essential, e.g. computers, handling of radio-active materials, spinning and weaving, paper manufacturing, rubber processing or any automatic or semi-automatic process.

Carbon film resistors. Aveley Electric Ltd., Ayron Road, South Ockendon, Essex.

This firm are sole agents for "Electronic" high grade carbon film resistors. The lacquer, resin, or glass coatings of all the resistors protect them from moisture. Variation with temperature is stated to be small, for the expansion of the lacquer coating is arranged to correspond with that of the ceramic rod, and the system of end-capping is accurately carried out. The resistors have a low noise factor, which is achieved by the special composition of the carbon layer, and close control of its uniformity and purity.

The resistors are divided into types suitable for different purposes. Notable features from the range include: ratings from 0·05 to 6 W; 1 Ω to 100 000 MΩ; initial tolerances from 0·1%; lacquer or resin-dip insulation; extra-low noise level and guaranteed temperature coefficients; and non-spiralled low-inductance types for radio-frequency use up to 3000 Mc/s.

New books

design of physics research laboratories. (London: Chapman and Hall Ltd., on behalf of The Institute of Physics, 1959) Pp. 108. Price 21*s*. (Available to members of the Institute at 15*s*.)

s book contains the proceedings of the symposium anized by the London and Home Counties Branch of The itute of Physics in November 1957. The symposium was narily devoted to the design of physics research labora- es but much of the information has a wider application, it is hoped that the book will be of value to all concerned the design of science laboratories in general.

he full proceedings of the symposium are given together 1 many of the diagrams and photographs which were sented as lantern slides. The chapter headings give some of the subjects covered in the volume: The architect and physics; Some problems in the planning of research laboratories; Recent trends in the design of American industrial research facilities; Services and facilities from the user's point of view; Buildings and services from the viewpoint of the laboratory maintenance engineer; Research on the design of laboratories.

The practical use of the microscope including photomicrography. By G. H. Needham. (Springfield, U.S.A.: Charles C. Thomas; London: Blackwell Scientific Publications, 1958.) Pp. xxiv + 493. Price £5 17*s*. 6*d*.

It is possible to extend a sincere welcome to this book without denying that certain reservations occur to one at the same time. In trying to obtain a balance, it is essential to allow for the very different "climates" in America and in this country with regard to the place occupied by specialized training. Mr. Needham's thesis is, in effect, to tell the student exactly what to do; give him pictures and tables, together with a modicum of "know-how" and all should then be well. There is no doubt that much practice and experience have gone into producing this large and very expensive book: it has something to say about most things (with two rather large exceptions to be noticed later) relating to microscopy in general. But an intelligent person, trained basically in geometrical and physical optics would deduce all this, and perhaps more, with the aid of a mere pamphlet of useful hints, rather than with nearly 500 pages of descriptive matter.

An example of the author's approach to a very real and subtle problem can be seen on p. 188 in the discussion on interference (conoscopic) figures in anistropic crystals. This effect, we are told, is produced by "convergent polarized light. . . ." In fact, the phenomenon follows from the passage through the specimen of *parallel* bundles (or pencils) of rays. The characteristic system of rings depends upon the inclination of any particular bundle with respect to the crystal axis. In work at the bench (and using the method for identification purposes), this is of little consequence, but the fundamental and aesthetic point has been missed.

Two major developments in physical microscopy are omitted. One is any reference to the use of polarized light for the study of opaque materials: the other, the technique of the von Federow universal stage—both the 5-axial and the 3-axial. It is well realized that the theory and practice of both these disciplines are enough to test the calibre of the ablest student, but it seems odd to omit them from such a comprehensive work, more particularly since their applications are becoming more and more obvious. F. I. G. RAWLINS

Physikalisches Taschenbuch. By H. EBERT. (Braunschweig: Friedr. Vieweg & Sohn, 1957.) Pp. viii + 544. Price DM. 22.80.

The attempt to put the essential facts as well as the numerical data for the whole of physics into a small book which fits into one's coat pocket is somewhat ambitious. Nobody will therefore be surprised if the result has proved wanting in certain respects. A physicist stranded on a desert island would undoubtedly find the book very useful, provided he would wish to follow his calling in the changed circumstances. He could well afford to overlook the inevitable lack of balance, the inevitable gaps and the inevitable inaccuracies. However, these shortcomings would be severely felt by those working under less difficult conditions and they will probably prefer to turn to the shelves of a library to which most of them have easy access.

Much effort and ingenuity must have been spent on producing this heavily loaded, closely printed examination crib, but one must doubt that a sufficient number of research workers get suitably stranded to warrant its publication. The referee cannot attempt to give an idea as to the contents of book, except by saying that it contains everything. He nev theless feels unable to recommend it to anyone but the abo mentioned minority. K. MENDELSSOHN

Technische Kunstgriffe bei physikalischen Untersuchung By E. v. ANGERER-EBERT. (Braunschweig: Frie Vieweg & Sohn.) Pp. viii + 369. Price DM. 18.80.

Prof. v. Angerer's little book on laboratory techniques w first published well over thirty years ago when it was us widely in physical laboratories, particularly by resear students. Since then the days of string and sealing wax ha largely disappeared and the research students have beco accustomed to use the products of a much expanded instr ment industry as well as to more liberal research funds. Ev so, a pocket book full of useful hints for soldering, gl blowing and sticking one thing to another can be strong recommended to any research worker even to-day.

On the other hand, the editor's efforts at streamlining t last two (post war) editions so as to fit into a new era can be considered an unqualified success. Particularly wh electronic gear is concerned, a pocket book can hardly d satisfactorily with the material. Other books will have t consulted in these cases and the publishers would be w advised in future editions to concentrate on good string a sealing wax recipes rather than to become too ambitious a too voluminous. K. MENDELSSOHN

British Journal of Applied Physics

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NOTES AND NEWS

Notes and comments

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Use of radial gratings in a small inclinometer

By A. Lewis,* G.I.Mech.E., and I. R. Young, B.Sc., Grad.Inst.P., Hilger and Watts Ltd., London, S.E.5

[*Paper first received* 13 *April, and in final form* 1 *September*, 1958]

Some of the factors involved in the choice of gratings for use in the digital measurement of angles are discussed. This problem is accentuated in the case of the instrument described by its small size and the decision, therefore, to use two complete circles for the gratings, instead of the less critical method using one circle and adjustable grating cursors. The tolerances which have to be achieved for satisfactory performance are considered and the instrument itself, a pendulous inclinometer intended to measure the pitch angle of wind tunnel models, is described.

INTRODUCTION

ge counting is one of the two main digital measuring iiques, the other being the coded scale method,(1,2) h is, however, difficult to apply where both high resolu- and small size are required, as a considerable number of tracks are needed, each with an associated detecting m.

a way analogous to that in which two linear gratings be used to produce linear moiré fringes,(3) two radial ngs can produce circular fringes, and it is with these, heir application to the measurement of angles in a small iometer, that this paper deals. This instrument is ded to measure the pitch of wind tunnel models under which must be known in their evaluation). In operation itput is set to zero with the model in a known position, the passage of the fringes, due to the relative motion of gratings in the instrument, is recorded to measure the of the model. Because of the materials of which the els are made, and their shapes, the only reasonable ence for such a measurement is gravity, and in the ument one grating is part of a pendulous unit while the is rigidly attached to the instrument body which moves the model.

digital measuring system is used for two main reasons. ly, the resolution required (1 part in 7200—measured igh 360°) is very high for a simple analogue device, and, ndly, this instrument is intended to be but one of many n integrated data-processing system,(4) feeding ulti- ly into a digital computer, and so all the information eferably in digital form.

ie small size of the unit is an important factor in the iation of the fringes. Though the maximum size available that of a cylinder 2 in. in diameter by 6 in. in length, it decided to make it as small as possible consistent with ining the specified resolution (3′ of arc over an angle of ° about the horizontal). The natural frequency of the ulous system was specified to be below 5 c/s, while the mum rate of tilt of the unit was to be 1° of arc/s, ing over an ambient temperature range of 0 to 45° C.

ie arguments used here will be related to the inclinometer specific problem, but they can be suitably applied to uments intended for many different tasks.

RADIAL GRATING TECHNIQUES

rcular moiré fringes are produced by two radial diffrac- gratings held very close together, and their properties, as Guild(3) has shown, can be derived by the application of classical optical theory. In this paper it will be assumed that all the gratings are used in transmission, and that all the rulings consist of alternate opaque and transmitting bars ("slit-and-bar" gratings), though neither of these assumptions is essential.

The simplest technique with radial gratings is to have one attached to the shaft close to which are held one or two small grating cursors which can be made fully adjustable and positioned so as to obtain the type of fringe which is desired. This technique becomes very difficult to apply when the circles and apertures are small.

Two signals are required from the instrument in order to determine the direction of rotation of the shaft. These outputs must neither be in phase nor π radians out of phase. A phase difference of $\pi/2$ is the ideal (Fig. 1 shows transmitting apertures positioned over circular moiré fringe rings in such a way as to obtain this).

In the inclinometer it was impracticable because of the small size to use grating cursors, by which signal phase may be readily adjusted. The system had to be designed so as to give the desired phasing and yet be practicable to make.

FORMATION OF FRINGES

Radial gratings may be used to provide three distinct types of fringe, which may be called (*a*) grid type, (*b*) vernier type, (*c*) moiré type. In discussing these the following terms will be used: (i) *Number of lines* in a ruling will be quoted as the number in a grating completed through 360°. (ii) *Angular pitch* is the angle subtended by a slit and bar at the centre (to all practical purposes). (iii) *Centre of rotation* is the intersection of the grating plane with the axis of rotation. (iv) *Eccentric error* is the linear displacement of the true centre of the radial grating and the centre of rotation. (v) *Radiality* is the direction of a ruling relative to a radius from the centre of rotation.

(*a*) *Grid type.* These are produced by two truly radial gratings with identical pitches. Their effect can be regarded as the superposition of two simple grids (until a resolution of 2–2500 lines/inch is reached and if the gap between the gratings is kept small). The phase relation needed in the signals can be obtained by ruling two segments of grating on one circle with the appropriate angular spacing. Contrast (see Table) is good and the circles are relatively easy to make on a conventional circular dividing engine.

(*b*) *Vernier type.* These fringes are produced by two truly radial rulings of different pitches and are themselves radial. The number of fringes in 360° is equal to the difference in the number of lines in the two circles. Contrast is less good than with grid type and the circles are rather more awkward to manufacture.

---

* Now at I.B.M. British Labs. Ltd., Hursley, Hants.

Contrasts obtained with various types of fringe. The contrast is the ratio of the maximum to the minimum signals and was measured using FT.420 Schwarz cells, and, in the first three cases the same type of lamp and similar optics. In all, white light was used

Fringe type	*Contrast*	*Remarks*
Grid	15–20 : 1	1000 lines/circle 2·5 in. diam.
Vernier	3·0–4·0 : 1	50 fringes/circle (1750 and 1800 lines/circle on 2 in. diam.). Width of aperture $\frac{1}{6}$th of fringe pitch.
Moiré	3·5–4·5 : 1	6000 lines/circle on 2½ in. diam. (Gratings shown in Figs. 1, 2.) Width of aperture $\frac{1}{6}$th of fringe pitch.
Grid	3·5–4 : 1	Inclinometer circles. 4320 lines/circle $\frac{3}{4}$ in. diam.

(*c*) *Moiré type*. These fringes are produced by two radial gratings (with, preferably, equal pitches), one, at least, of which has its rulings tangential to a small circle about its centre. Grating cursors can, of course, be twisted over a radial grating to give segments of fringe rings, but it is necessary to use this technique to obtain the complete ring fringes shown in Fig. 1. These rings are degraded if the illumination is not parallel or normal to the plane of the gratings or if the circles are eccentric. (Fig. 2 shows the gratings shown in Fig. 1 illuminated by a parallel beam incident at an angle of about 15° to the normal).

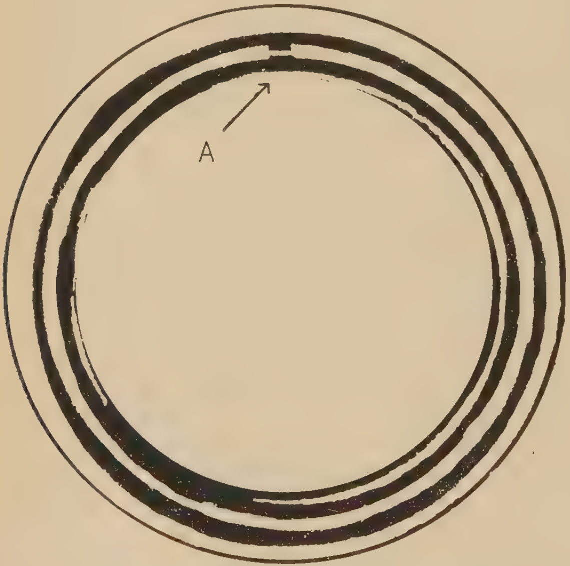

Fig. 1. Photograph showing circular moiré fringes, with the apertures used in fringe counting marked

The pitch of these fringes may be derived using arguments like those of Guild[3] and is given by $W = R^2\psi/R_1 + R_2$, where (as shown in Fig. 3) W is the fringe pitch, ψ the angular pitch, R_1 and R_2 the radii of the small ruling circles, and R the mean radius of the fringe being considered.

Using fixed apertures, it would be necessary to control and R_2 very tightly to obtain correct signal phasing. In case of the grating shown in Figs. 1 and 2, R_1 = $= 0{\cdot}0038$ in., and, if it were intended to make such grat for use in an inclinometer, these values would have to controlled to at most 0·001 in. This is difficult on the t

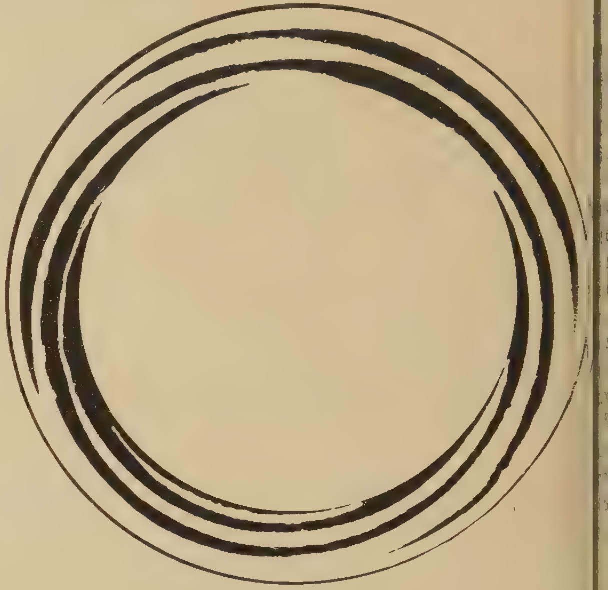

Fig. 2. Circular fringe rings distorted by illuminatio that is not normally incident

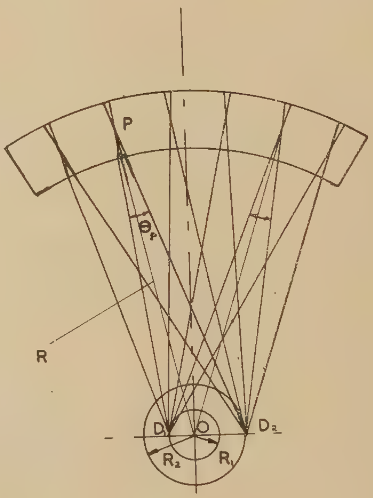

Fig. 3. Diagram for discussion of the formation of moi fringes

of engine used to make the gratings, and as the contrast w this type of fringe is less good than that of grid type frin obtained from the relatively coarse gratings needed in t problem, it was decided to use the latter.

TOLERANCES

There are a number of factors that are important in us the gratings in the instrument which will now be consider

Distance between the gratings. If the gap between the es is too great, contrast will be seriously reduced. ording to Guild,(3) the main phase term ϵ, introduced by gap between the gratings for a beam diffracted into the order by the first one is

$$\epsilon = \frac{2\pi t}{\lambda} \sin \beta_n$$

re t = distance between gratings and β_n = diffraction e for nth order light of wavelength λ.

or the relatively coarse inclinometer gratings (about) lines to the inch), the significant order sequences(3) for action at the two gratings are (0, 0) and (1, −1) or , 1). For satisfactory contrast, the phase difference veen the (0, 0) and either of the other sequences should exceed about $\pi/4$, giving the approximate relationship $p^2/4\lambda$, where p = linear pitch of the gratings. Taking red light best suited for the cells used, this gives a value of about $2{\cdot}5 \times 10^{-3}$ in. In practice, in the instrument, gap was held to about $0{\cdot}5 \times 10^{-3}$ in.

i) *Eccentricity of gratings.* This is the most difficult or to control and is vital with any of the techniques for ffects the accuracy of measurement, and can affect the sing of the output signals so badly as to destroy any blance of coherent counting.

ualitatively consider Fig. 4, which shows two gratings n which, it will be assumed, grid type fringes are to be ained. O is the centre of the fixed circle, while the moving le (that attached to the shaft) has an eccentric error such t its centre is at A. Grid type fringes are produced at nd Q (assuming r to be so small relative to the radius of ruling that the difference in pitch between the gratings is ligible), but moiré fringes appear at R and S. With the tre at B, the situation is reversed with moiré type at P Q and grid type at R and S.

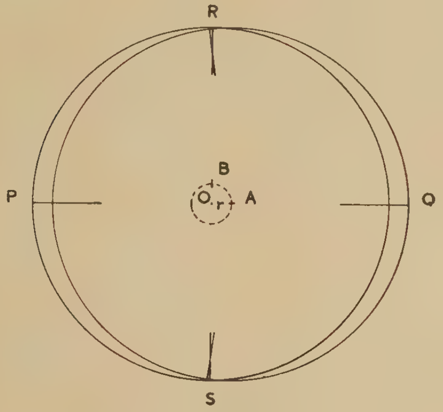

Fig. 4. Illustration of the effect of eccentricity

s the effect of eccentricity on phasing is the more critical the inclinometer, this will be treated to the exclusion of t on measuring accuracy. In manipulating the two signals m the unit, the roughly sinusoidal outputs are squared by mitt trigger circuits after amplification. The counting ses are derived by differentiation, and are gated with d.c. pled signals from the triggers to determine the direction rotation. If the edges of the square waves derived from two outputs approach too closely to each other, i.e. if the se difference approaches 0 or π, major ambiguities can e.

uantitatively the total eccentric error, r, which is permissible with detectors spaced at 90° round the circle $= \pi RT/2n$, where T is the angular tolerance on phase measured as a fraction of $\pi/2$, R is the mean radius of the grating, and n the number of rulings in the circle.

T must be less than 1 but, in practice, it is desirable to keep it below 0·5. For the inclinometer, $R = 0{\cdot}375$ in. and $n = 4320$, so that $r = 0{\cdot}00007$ in. (approximately).

In the inclinometer the grating apertures are only 60° apart, which increases the permissible value of r by 1·15, but even with this the tolerance on eccentricity is extremely difficult to meet. In practice, the phasing was found to vary by about $\pi/4$ over the range of measurement.

(iii) *Alinement of optics.* It is desirable to use normal, parallel incident light, though as there is a gap between the gratings, it is possible to deflect the beams for the two apertures as a phasing adjustment. However, if the gap between circles is not uniform (in the inclinometer it varies by about 0·0002 in.), an additional source of phase variation is introduced by this. Contrast is badly affected by non-parallel light and it is this effect, due to the very small, fairly steeply curved lenses and relatively large source area used, which is the main reason for the contrast in the inclinometer being relatively small compared with that for the other grid type gratings recorded in the Table.

Movement of the bulb filament as it ages or warms up can be troublesome, resulting as it does in changes of both contrast and phasing. In the inclinometer, therefore, the collimating lens has a small ground glass window and red filter at its focus.

(iv) *Other factors.* The maximum angular error between any two lines on the circles used in the instrument is less than 10″ of arc, allowing for reproduction errors in preparing them from the masters. This is unimportant in an instrument whose resolution is 1·25′ of arc. Random defects, such as broken lines or pinholes and scratches either on the masters or copies, are tolerable as long as the defects do not exceed about 10% of the area of a grating aperture. Nothing can be done to "spot-out" any blemishes because of the closeness with which the circles are run.

In operation there is a likelihood of missing counts if the speed of rotation is too high or there is excessive vibration. Trouble due to these can be eliminated by limiting the rotation speed and by damping (which may be done magnetically if a copper vane is attached to the shaft).

The risk of lamp failure is minimized by using high quality bulbs and heavily under-running them. Only one bulb is used in the instrument to reduce heating, to which the photoconductive cells are sensitive, and lessen the chance of an unnoticed failure.

DESCRIPTION OF THE INSTRUMENT

The moving grating (G_2, Fig. 5) is mounted on a brass bush on a hardened steel pivot with conical ends. The pendulum W is made of brass and is a 60° segment of a 1 in. diameter circle, suspended immediately behind the circle on the opposite side to the rulings (which are not shown, though the apertures A_1, A_2 on the fixed circle are marked).

The pivots run in artificial ruby bearings, one of which is spring-loaded and the other, D, held in an adjustable sleeve so that the gap between the gratings may be controlled.

The optical system is sketched in Fig. 5. The lamp is an Atlas type with a rated life of 1000 hours at 14 V, though in the instrument it is run at 10 V and is mounted behind the small aperture (at B) and red filter. The collimating lens L_1 is a small segment cut out of a complete one and is positioned so that it produces a beam parallel to the axis of the cylinder. The right-angled prisms P_1, P_2, reflect the light on to the grating apertures A_1, A_2, which are positioned 60° centre to centre apart. Prisms P_3, P_4, reflect the light on to the collector lens segments L_2, L_3 (which form images of the lamp aperture on the cells) and prisms P_5, P_6. The technique used for the lenses was employed because the flat edges make mounting comparatively simple, as all that is needed is a flat base plate and a clamping spring.

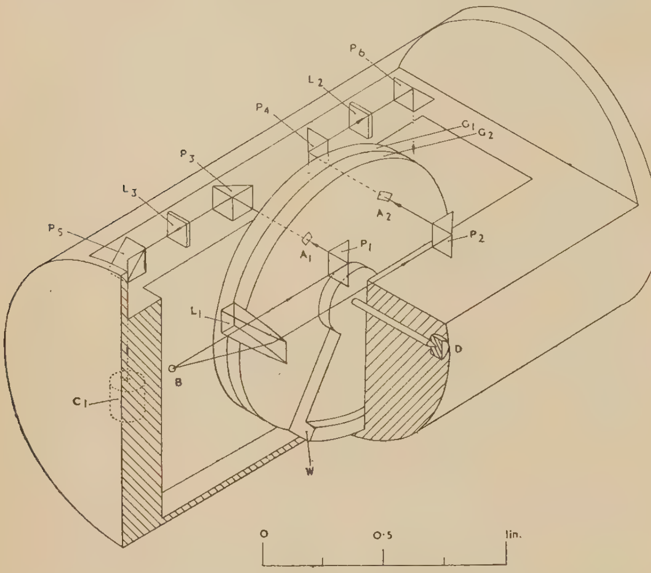

Fig. 5. Construction of the inclinometer, sectioned to show the position of the cells, gratings and pendulum and one of the jewelled bearings

The photocells, which in the present unit are Hilger FT. Schwarz cells, are mounted in the body of the instrum facing up towards the prisms (C_1). These cells are of high sensitivity but limited response speed. They are with a series load resistor and an applied voltage of 20 V

The signals are measured across the loads and ampli (by a 12 AX7) before being fed into the Schmitt trig circuits (Fig. 6). These circuits have to have rapid switch and low backlash (in practice this was reduced to be 0·15 V) at the input from the cells—or to below 5% of signal amplitude.

To derive two counts from each fringe, antiphase sig are taken from each of the trigger circuits, one pair coupled, the other differentiated pulses, and fed to the sh suppressor cut-off pentodes (6 F33). Two of these prov forward counting pulses, the others reverse, which are pas to an Ericsson reversible register type 135A. By d.c. coupl and deriving differentiated pulses from both trigger circu four counts can be derived from the passage of a fringe.

PERFORMANCE

The present maximum resolution of the instrument 1·25′—or 1 part in 17280 in 360°. The instrument repe its zero to within ±1 count, though, to achieve this, it necessary to reduce static friction in the bearings to a v low level.

At this moment, the greatest relative angular speed of gratings which gives reliable readings is about 3° per sec (i.e. between 70 and 75 counts per second at two counts 140 counts per second at four counts per line). The pendul has a period of $\frac{1}{4}$ s and errors can result from oscillatio with an amplitude greater than about 0·4°. The ov dimensions of the present unit, including the case, are $1\frac{1}{4}$ in diameter by $2\frac{1}{2}$ in. long. A photograph is shown in Fig.

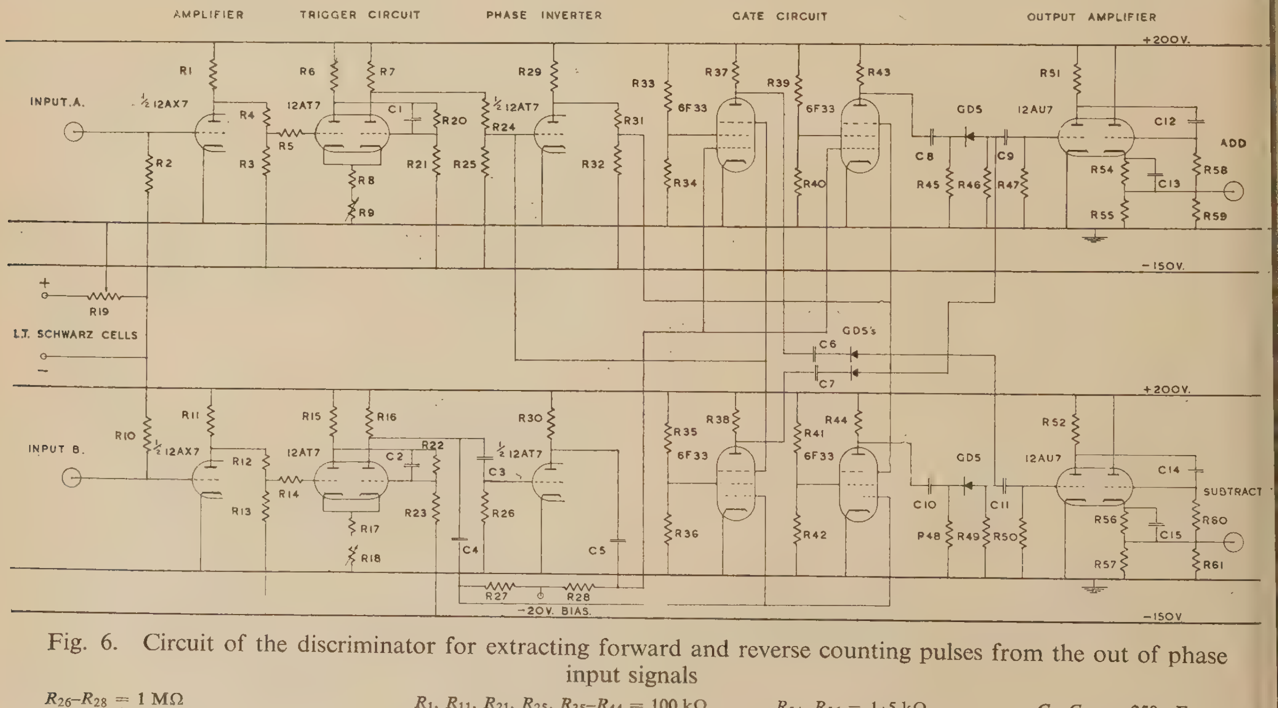

Fig. 6. Circuit of the discriminator for extracting forward and reverse counting pulses from the out of phase input signals

R_{26}–R_{28} = 1 MΩ
R_3, R_4, R_{12}, R_{13}, R_{24}, R_{25}, R_{58}, R_{60} = 500 kΩ
R_2, R_{10} = 550 kΩ
R_{45}–R_{50} = 220 kΩ

R_1, R_{11}, R_{21}, R_{25}, R_{35}–R_{44} = 100 kΩ
R_{20}, R_{23} = 560 kΩ
R_{59}, R_{60} = 50 kΩ
R_6, R_{15}, R_{51}, R_{52} = 22 kΩ
R_5, R_7, R_{14}, R_{16}, R_{55}, R_{57} = 10 kΩ

R_{54}, R_{56} = 1·5 kΩ
R_8, R_{27} = 500 Ω
R_{19} = 50 kΩ pot.
R_9, R_{18} = 1 kΩ pot.

C_1, C_2 = 250 μF
C_3–C_{12}, C_{14} = 0·01 μF
C_{13}, C_{15} = 25 μF

DISCUSSION

ıe performance of the instrument can be improved in main directions—speed and resolution. In the case of ormer, experiments with the gratings used indicate that o-transistors can be used (Mullard OCP71 were used ıe tests), fairly easily so, if the apertures are extended optics rearranged and improved.

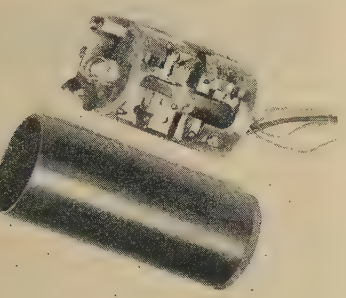

Fig. 7. Photograph of the inclinometer

›solution is limited by the mechanical precision of nting the gratings and their reproduction. The former d be improved if there were more space available, and the r assisted by using photographic copies rather than the used at present which are photo-etched in a chemically ›sited silver. The grating masters are made on photo-hic plate using a modified circular dividing engine and hen printed on to suitably cut blanks. To obtain greater utions these could be coated commercially or in the ‹shop, using, for example, a photographic stripping or vford$^{(5)}$ emulsion.

CONCLUSION

The instrument described here uses a fringe counting technique to measure the attitude of wind-tunnel models. The various methods of producing fringes have been outlined so that the reasons for the particular choice made can be explained. The instrument itself is pendulous, but this is because of the application for which it was designed and is not essential to the method.

ACKNOWLEDGEMENTS

Our thanks are due to the Directors of Hilger and Watts Ltd. for permission to publish this paper, and to Dr. A. C. Menzies, Mr. V. W. H. Towns and Mr. D. S. Evans for their encouragement. We are greatly indebted to Mr. Lowne of the Lowne Electric Clock and Appliance Co. Ltd., who designed the bearing mechanism and built the whole instrument. This instrument was made to Ministry of Supply Contract No. S/Inst/19 438/CB.16(*a*), and we are grateful to Mr. J. F. M. Scholes of R.A.E., Bedford, who suggested the problem and advised us throughout.

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Resistance strain gauges of low temperature sensitivity

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[*Paper first received* 18 *August, and in final form* 15 *October*, 1958]

Strain gauges manufactured from a series combination of Nichrome* and Advance† wires may be used in quarter-bridge circuits to measure static strains where the temperature is slowly varying. The average temperature drift corresponds to 20 lb/in.^{2} × °C on steel and 2·5 lb/in.^{2} × °C on dural and the sensitivity drop is less than 5% up to 250° C. When used in a full-bridge circuit the drift should be negligible.

INTRODUCTION

; well known that the resistance strain gauge shows a ›erature sensitivity such that a small change in tempera- produces a signal equivalent to a large strain. Conse-ıtly the measurement of static strains under conditions of ing ambient temperature demands careful technique and use of circuits usually incorporating the "T-gauge" or a ımy (i.e. unstrained) gauge. Compensation methods ıble for laboratory use have been discussed by Senior$^{(1)}$ by Urwin and Swainger.$^{(2)}$

Iany cases arise where the use of such complex circuits er service conditions is undesirable—for instance, in the measurement of airframe stresses in flying aircraft. This paper describes the development of a strain gauge capable of being used at temperatures up to 250° C and having a temperature sensitivity such that it can be used in a quarter-bridge circuit. This strain gauge was required for use on aircraft structures and the working temperature ranges were defined as 0 to 250° C used on steel, and 0 to 150° C used on dural.

A lecture on this subject, using much of the data presented in this paper, was given by R. D. Trumper and A. Fagg to the Cranfield Conference of the Stress Analysis Group of the Institute of Physics in September 1956.

The temperature drift characteristics of standard type strain gauges are shown in Fig. 1. It is immediately apparent that a combination of Nichrome and Advance wires could be made to give a temperature coefficient of resistance approaching zero. This principle was discussed as long ago

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80% Ni–20% Cr alloy manufactured by Johnson, Matthey Co. Ltd., London, E.C.1.

60% Cu–40% Ni alloy manufactured by the British Driver-is Co. Ltd., Manchester.

as 1940(3) but has been generally disregarded on the grounds that the properties of commercial wires and the manufacturing difficulties result in gauges having an inconsistent degree of compensation. (To the author's knowledge, the only commercially obtainable self-compensating strain gauge is that offered by the Baldwin-Lima-Hamilton Co., of America. The "Avro" strain gauge, made by Farnell Instruments Ltd., of Wetherby, offers a degree of compensation by the use of a thermistor in the circuit.) The simplicity of the two-wire gauge was, however, so attractive that an investigation was undertaken into the degree of compensation obtainable and the variability in manufacture.

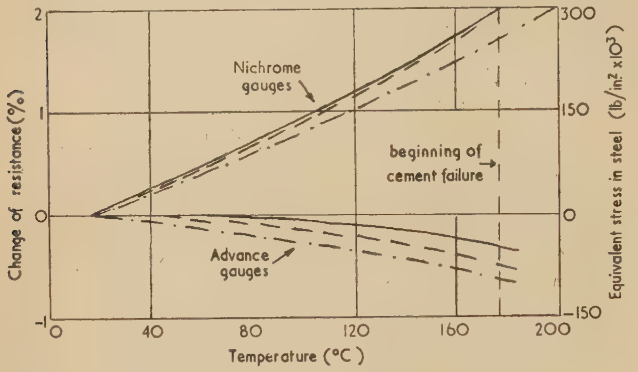

Fig. 1. Temperature drift of Advance and Nichrome Bakelite bonded strain gauges

———— attached to dural
—·—·— attached to steel
— — — unmounted

PRELIMINARY EXPERIMENTAL WORK

Nichrome and Advance were chosen to be used in a series combination because of their general suitability for strain gauge work, their high gauge factors and their availability. The adhesive used was Bakelite G.11091. This gave a linear temperature drift up to 140° C after normal curing at 100° C for two hours. This was acceptable for dural but for working on steel it was found that the linear range could be extended to 250° C by post-curing at 260° C for thirty minutes. The investigations were made on commercial mild steel and dural to specification D.T.D. 610 B.

Following the establishment of the characteristic curves of Fig. 1 two trial batches of two-wire gauges were prepared; that for steel having resistance ratios Advance/Nichrome in the range 2·8 to 3·8 and that for dural having resistance ratios in the range 7·5 to 8·5. The results given by these groups of gauges are shown in Figs. 2 and 3. The resista ratios 3.52 (steel) and 8.05 (dural) gave the best drift va and were adopted as standard for subsequent work. Tl combinations show average temperature coefficients their working ranges of $1 \cdot 27 \times 10^{-6}/°\,C$ (= 20 lb/in.^{2} × on steel, and $0 \cdot 45 \times 10^{-6}/°\,C$ (= 2·5 lb/in.^{2} × ° C) dural. That exact compensation could not be achieve attributed to variations of temperature coefficient of constituent metals with temperature.

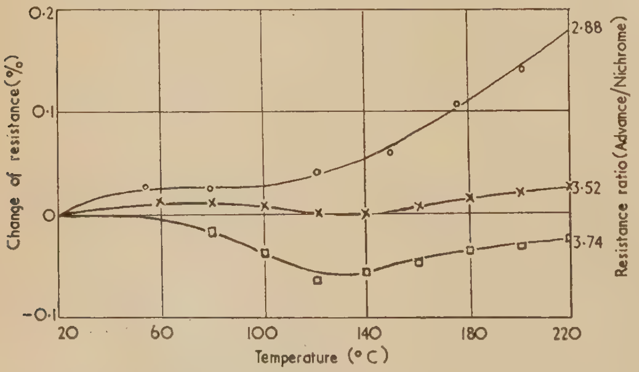

Fig. 2. Temperature drift of two-wire gauges on steel

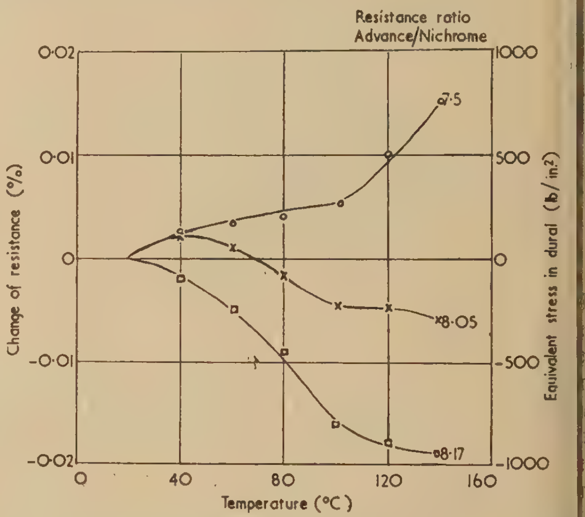

Fig. 3. Temperature drift of two-wire gauges on dura

CHARACTERISTICS OF THE TWO-WIRE GAUGE

Fig. 4 shows a comparison, made on mild steel, between two-wire gauge and Nichrome gauges used in standard co pensating arrangements. Readings were made only a

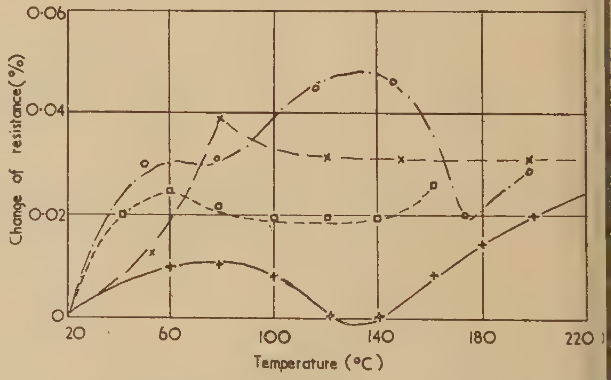

Fig. 4. Temperature drift of four compensated systems on steel

+———— Two-wire gauge—quarter-bridge
×— —·— — "dummy" gauge half-bridge circuit
○—·—·— T-gauge half-bridge circuit
□– – – – – Baldwin-Lima-Hamilton EBD–4S gauge—quarter bridge

long periods had been allowed for oven temperatures stabilize. The performance of a Baldwin-Lima-Hamilt EBD-4S self-compensating gauge has been included in t figure.

The variation of gauge factor, i.e. the ratio of the fractio change in resistance of a strain gauge to the change in t applied strain, with temperature is shown in Fig. 5 to be l

5% up to 250° C. This is a feature of the high-tem- ture curing of the cement rather than of the gauge. The curing of the Bakelite cement needed for compensation o these temperatures has a disadvantage in that the nt becomes brittle and the gauge detaches from the l surface at strains of the order of 0·25%, corresponding resses of 75 000 lb/in.^{2} (steel) or 25 000 lb/in.^{2} (dural).

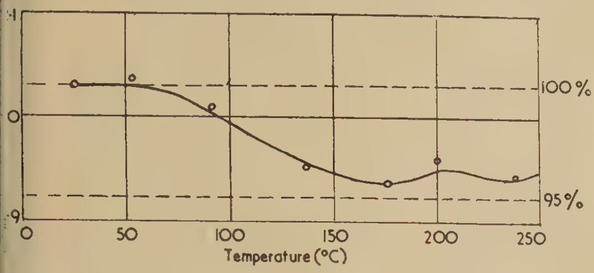

Fig. 5. Variation of gauge factor with temperature

ne two-wire gauge is very sensitive to changes in the ficient of expansion of the base metal. This effect is trated in Fig. 6 which shows the drift of two identical wire gauges attached to steels of different compositions. difference between the quoted and observed performances e Baldwin EBD-4S gauge is attributed to the gauge being l on a base metal differing from that for which it was pensated.

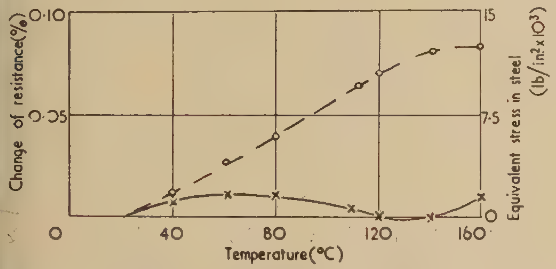

Fig. 6. Effect of base metal on temperature drift

×——— gauge attached to mild steel
○— — — gauge attached to spring steel

a gauge compensated for use on a base metal of coeffi- t of expansion e_1 is attached to an alternative base metal ing a coefficient of expansion e_2, the rate of change of stance with temperature is

$$dR/RdT = G(e_2 - e_1) \qquad (1)$$

uming $G_n = G_A = G$,

re dR/R = fractional change in resistance
dT = change in temperature (° C)
G_A, G_N = gauge factors of Advance and Nichrome, respectively
e = coefficient of linear expansion (° C^{-1}).

pplication of this equation to the curves of Fig. 6 indi- s that the difference in expansion coefficient of the two ls is approximately $3{\cdot}6 \times 10^{-6}$/° C. It is clear that for e compensation from a single gauge it must be very ely matched to its base metal, but when used on a wide ge of metals its temperature coefficient is still relatively and it may be used to advantage.

he appropriate resistance ratio for a combination to be l on a particular metal is given by

$$K = -[a_N + G_N(e - e_N)]/[a_A + G_A(e - e_A)] \qquad (2)$$

where K = the ratio of the resistance of Advance component to the resistance of Nichrome component in a series combination, and
a_A, a_N = temperature coefficients of resistance (° C^{-1}).

This equation neglects the second-order variations in temperature coefficients which do appear significant when approximate compensation is achieved.

MANUFACTURE OF THE GAUGE

The two-wire gauges are standard paper-backed types made on the flattened helix principle. A few turns of Nichrome and Advance wires, both 0·001 in. diameter, are wound on a paper former adjacent to each other and cemented with Bakelite cement J.11185. The former is subsequently flattened and a relatively wide (0·025 in.) copper-nickel strip is cemented between the two windings. One end of each wire is welded to this strip and the wires are then trimmed to their correct lengths before adding lead-out strips. Paper insulation is placed on each side and the whole sandwich pressed and heated for thirty minutes.

Although the manufacture of such gauges is slow, and dependent for its success on the skill of the operator, it has been found possible to make them with remarkable consistency. Of the last batch of twenty-seven gauges for use on steel, the mean resistance ratio was 3.52 and the standard deviation 0·007. One reel of each wire was used in their manufacture and lengths for each gauge taken at intervals through the reel. These gauges followed the characteristics shown in Figs. 2 and 4 within some 10%. A check on the temperature coefficient of resistance shown by each reel of wire is necessary and any appropriate changes in the resistance ratio can then be made. No other precautions appear to be needed to make this type of gauge a regular engineering tool.

CONCLUSIONS

The simple combination gauge as described in this paper has a temperature sensitivity, in the worst region of its characteristic curve, less than 5% of that of conventional Nichrome strain gauges. The average temperature drift corresponds to 20 lb/in.^{2} × ° C on steel and 2·5 lb/in.^{2} × ° C on dural and the sensitivity drop is less than 5% up to 250° C.

Using this technique static strains may readily be measured by quarter-bridge circuits and the accuracy of full-bridge or other compensating circuits greatly increased. Commercial quality wires have proved entirely satisfactory and no difficulty has been found in producing gauges with consistent properties.

ACKNOWLEDGEMENTS

The author wishes to thank the Technical Director, Fairey Aviation Company, for permission to publish this paper; Mr. R. D. Trumper, Test Superintendent, for his constant help and advice; and Mr. L. Brooke Edwards of the Baldwin-Lima-Hamilton Corp., who kindly provided some of their gauges and adhesives for investigation. He further wishes to record his debt to Mr. A. Fagg, Head of the Strain Gauge Department, who collaborated fully in this work and upon whose skill and experience he was largely dependent.

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Automatic scanner for electrophoresis and chromatography paper strips

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[*Paper first received* 21 *July, and in final form* 17 *September*, 1958]

A device for scanning electrophoresis and chromatography paper strips is described. A pen recorder traces the curves of the optical density, integral of the optical density, radioactivity intensity and integral of the radioactivity intensity as a function of position of the paper strip. The scanning is carried out automatically.

Scanning of dyed chromatography and electrophoresis paper strips is tedious and takes a long time. To shorten the procedure of scanning, a device has been designed which works almost automatically. This device measures the optical density and the radioactivity of paper strips. Optical density is defined as the logarithm of the ratio of incident to transmitted light and, according to the Lambert–Beer law, is a measure of the concentration of light absorbing material. Therefore, to obtain an output voltage proportional to concentration, a photomultiplier circuit which has a logarithmic characteristic has been used.(1, 2, 3, 4)

To find the total amount of substance present on the strip, integration is carried out. It is also possible to find the contribution of a single spot to the total amount. Some spots may be radioactive. The described device enables radioactivity intensity measurements and measurements of the total amount of radioactivity present on the strip to be made.

MECHANICAL CONSTRUCTION

The mechanical construction can be seen in Fig. 1. The paper strip is taped on a transparent paper carrier made of Plexiglass *a*. The carrier is suspended on a thin wire rope *b* wound on a wheel *c* fixed to an axis *d*, which can be coupled with the driving axis *e* of the pen recorder by a sleeve coupling *f*. The diameter of the wheel is chosen so that the moving speeds of the paper strip and the recording chart are same. The weight of the carrier is balanced with a count weight *g* to avoid loading of the pen recorder driving mot A pen recorder (8 V, 2 mA) with changeable speeds is us When photometric measurements are made the paper carr with the paper strip passes through a chamber with a pho multiplier tube *h*. When radioactivity is measured, it pas through a lead chamber with a Geiger–Müller counter *i*.

The chamber for the photo-scan and the paper carrier schematically shown in Fig. 2. A lamp supplied from accumulator serves as the light source of constant lig intensity. The light intensity can be adjusted by a varia resistor in series with the lamp. In order to obtain a lig spectrum band narrow enough, interference filters are use

The paper carrier is covered on its edges by a non-tra parent material. The uncovered part in the middle is sligh narrower than the scanned paper strip. The width of t uncovered part must, of course, be constant to make su that the width of the area through which light passes constant. When the scanning is ended, the paper carri

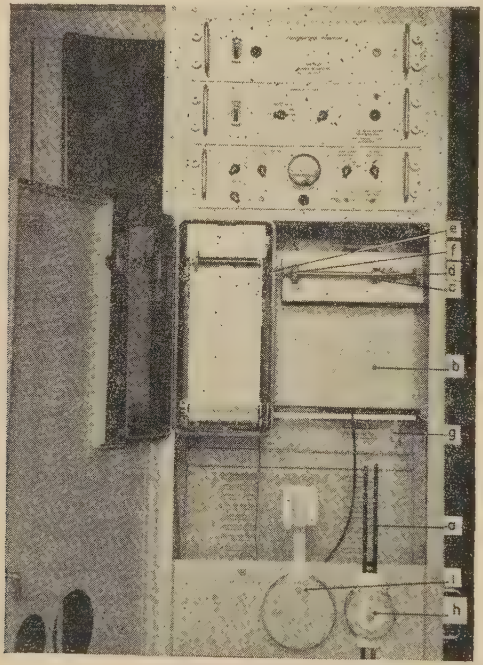


Fig. 1. Automatic scanner for electrophoresis and chromatography paper strips

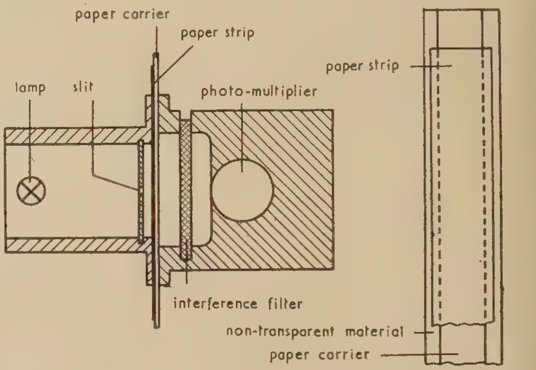


Fig. 2. Chamber for photo-scan and paper carrier

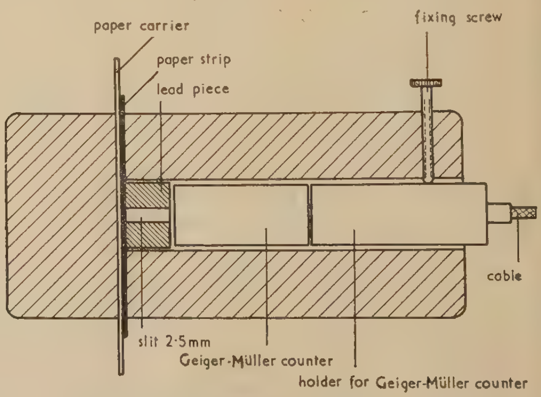


Fig. 3. Shielding chamber with Geiger–Müller counter for radioactivity scan

its weight switches off the driving motor and switches an alarm.

he shielding chamber with the Geiger–Müller counter for radioactivity scan is shown in Fig. 3. The Geiger–Müller nter can be placed at different distances from the paper by inserting different lead pieces with slits. The smallest ance between the G.M. counter and the paper strip is ut 1 mm.

ELECTRONIC CIRCUIT

he block diagram of the electronic circuit is shown in 4. The electronic system consists of two parts: the part photo-scan and the part for radioactivity measurements. h parts have a common output stage with a pen recorder.

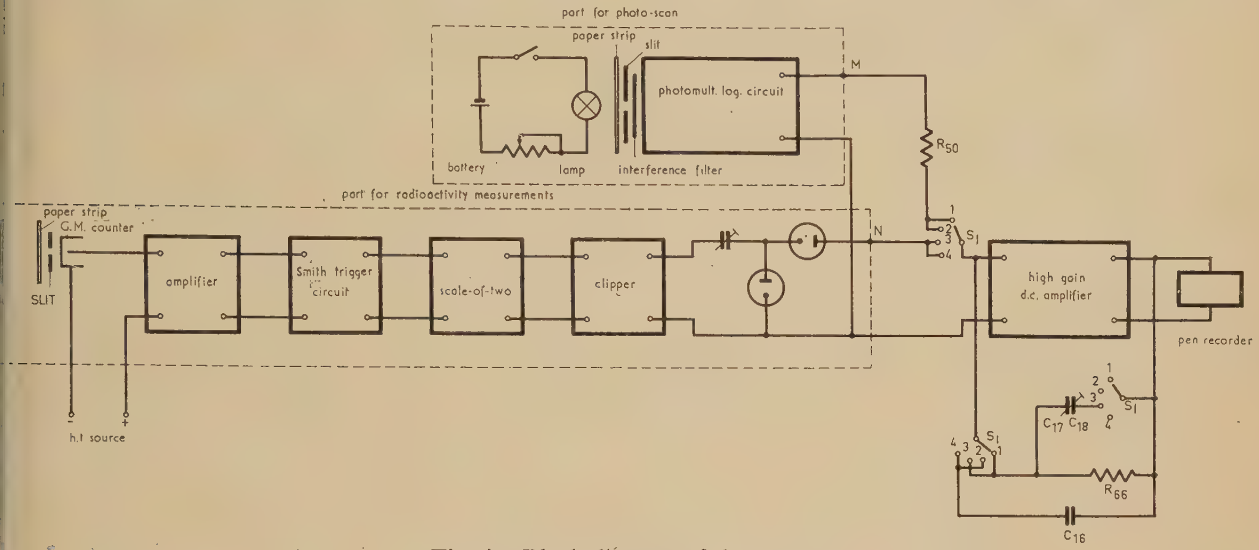


Fig. 4. Block diagram of the scanner

mode of operation of the device is selected by the switch position 1, photometry; position 2, photo-integration; ition 3, radioactivity intensity measurements; position 4, ioactivity integration:

. *Photometry.* Light from the light source passes through paper strip and falls on a photometric device, which gives output voltage proportional to the optical density. This tage is applied to the common output stage which operates a d.c. amplifier with the overall gain $G \simeq -R_{66}/R_{50}$. output voltage from the d.c. amplifier is applied to a recorder and is recorded as a function of the paper strip ition.

. *Photo-integration.* The photometric part is connected he output stage, which operates as a Miller integrator and es the output voltage proportional to the time integral of input voltage.

. *Radioactivity intensity measurements.* The part for ioactivity measurements is connected to the output stage the whole device operates as a counting ratemeter.(5)

. *Radioactivity integration.* The part for radioactivity asurements is connected to the output stage. The "diode np" circuit charges the capacitor C_{16}, and the output tage is proportional to the total number of pulses eived.

The circuit diagram of the instrument is shown in Fig. 5. circuit of the photometric part is similar to that described Sweet.(1, 2) The photomultiplier V_5 operates with nearly stant plate current because of a feedback to its dynodes ough V_7. Any increase of the incident light tends to produce an increase of the plate current. This increase produces a larger negative bias for the tube V_7, reducing its cathode current and voltage on R_{41}. The voltage on the divider chain R_{31}–R_{39} is therefore also reduced, tending to keep the plate current of V_5 constant. The output voltage of this circuit taken from the point M is nearly a logarithmic function of the incident light intensity. To improve its logarithmic characteristics, the divider R_{47}, R_{48} and R_{49} in series with the diode V_8 have been added.

When the incident light passes through the undyed portion of the paper, the point M has to be at ground potential. This can be adjusted by the potentiometer R_{45} (S_{k1}—open).

The voltage from the point M is applied through R_{50} to the d.c. amplifier (V_{10} and V_{11}) which has a high gain obtained by positive feedback (R_{53}, R_{55}, R_{58}). The zero adjustment of the amplifier is made by the potentiometer R_{60} in connexion with a sensitive instrument I which can be switched on by the push-button B. For zero adjustment of the amplifier, when photometry or photo-integration is carried out, the switch S_{I} has to be in position 1.

To avoid noticeable discharging of the capacitor C_{16} when the output stage operates as a Miller integrator and integration is made over a long time, a compensation feedback from the plate of V_{11} to the point M through the resistor R_{56} is used. The sensitivity of photometry and photo-integration can be selected by the switch S_{IV}.

When radioactivity measurements are made, the pulses from the Geiger–Müller counter after amplification are applied to the input of the pulse shaper (V_1). The output pulses from V_1, differentiated by C_2–R_8, trigger through the diode V_2 the "scale-of-two" V_3. These pulses are applied to the cathode-coupled clipper V_4, which gives pulses of constant amplitude to the "diode pump circuit" V_9.

When the switch S_{I} is in position 3 the whole instrument operates as a counting ratemeter. The instrument has six ranges: 3, 10, 30, 100, 300, 1000 pulses/second, which can be selected by the switch S_{II}. The ranges can be accurately adjusted by the potentiometers R_{25}, R_{26}, R_{27} and trimmers C_{12}, C_{14}. The time-constant of the ratemeter is selected by the switch S_{III}. The zero adjustment of the instrument as ratemeter is made by the potentiometer R_{60} with the switch S_{III} in position 1. In this position of S_{III} the resistor R_7 is added in series to R_6 to block the input of V_1.

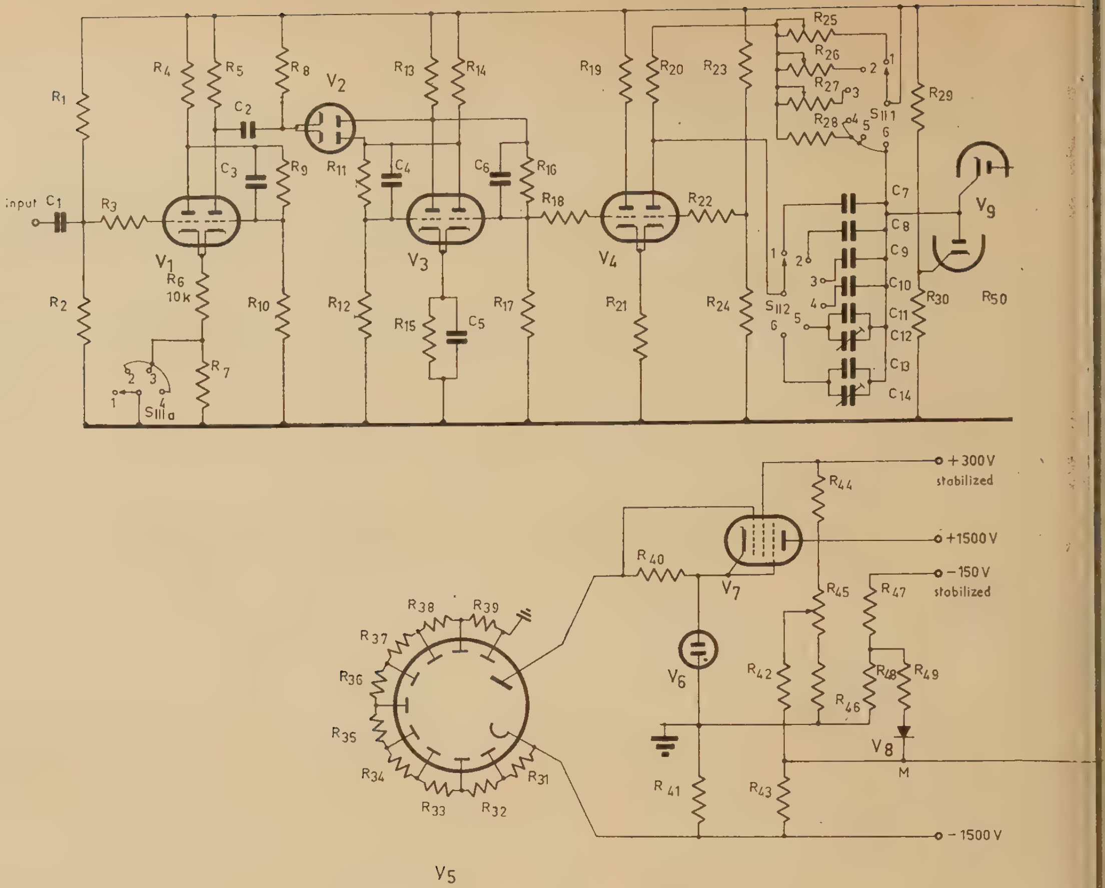


Fig. 5. Circuit diagram of the scanner

R_1 = 200 kΩ
R_2 = 100 kΩ
R_3 = 1 kΩ
R_4, R_5, R_6 = 10 kΩ
R_7 = 60 kΩ
R_8 = 50 kΩ
R_9 = 200 kΩ
R_{10} = 80 kΩ
R_{11} = 200 kΩ
R_{12} = 80 kΩ
R_{13}, R_{14}, R_{15} = 10 kΩ
R_{16} = 200 kΩ
R_{17} = 80 kΩ
R_{18} = 1 kΩ
R_{19}, R_{20} = 15 kΩ
R_{21} = 10 kΩ
R_{22} = 1 kΩ
R_{23} = 200 kΩ

R_{24} = 60 kΩ
R_{25}, R_{26}, R_{27} = 2 kΩ
R_{28} = 1 kΩ
R_{29} = 300 kΩ
R_{30} = 5 kΩ
R_{31}–R_{39} = 100 kΩ
R_{40} = 100 MΩ
R_{41} = 150 kΩ
R_{42} = 15 MΩ
R_{43} = 20 MΩ
R_{44} = 100 kΩ
R_{45} = 100 kΩ, w.w.
R_{46} = 200 kΩ
R_{47} = 80 kΩ
R_{48} = 25 kΩ
R_{49} = 10 MΩ
R_{50} = 50 MΩ
R_{51} = 300 kΩ

R_{52} = 70 kΩ
R_{53} = 150 kΩ
R_{54} = 1·5 MΩ
R_{55} = 1 MΩ
R_{56} = 100 MΩ
R_{57}, R_{58} = 1·5 MΩ
R_{59} = 1·5 kΩ
R_{60} = 2 kΩ
R_{61} = 150 kΩ
R_{62} = 5 kΩ
R_{63} = 70 kΩ
R_{64} = 2 kΩ
R_{65} = 200 Ω
R_{66} = 10 MΩ
R_{67} = 10 kΩ
R_{68} = 4 kΩ
R_{69} = 8 kΩ
R_{70} = 16 kΩ

R_{71} = 3 kΩ
R_{72} = 6 kΩ
R_{73} = 2 kΩ
R_{74} = 10 kΩ
R_{75} = 8 kΩ
R_{76} = 15 kΩ
R_{77} = 25 kΩ
R_{78} = 250 kΩ
R_{79} = 20 kΩ
R_{80} = 150 kΩ
R_{81} = 1 MΩ
R_{82} = 500 kΩ
R_{83} = 7 kΩ

C_1 = 0·01 μF
C_2, C_3 = 30 pF
C_5 = 0·01 μF
C_4, C_6 = 50 pF

C_7 = 0·01 μF
C_8 = 0·003 μF
C_9 = 0·001 μF
C_{10} = 300 pF
C_{11} = 70 pF
C_{12} = 35 pF
C_{13} = 10 pF
C_{14} = 35 pF
C_{15} = 0·001 μF
C_{16} = 12 μF
C_{17} = 3 μF
C_{18} = 0·5 μF
C_{19} = 10 μF

V_1 = ECC40
V_2 = EB91
V_3, V_4 = ECC40

V_5 = 931A
V_6 = 85A2
V_7 = EL81
V_8 = S–35
V_9 = EB91
V_{10} = ECC81
V_{11}, V_{12} = ECC40
V_{13} = EBL21

R = relay 1600 Ω

I = meter 0–1 mA

S_{I} = 6-pole, 4-way
S_{II} = 2-pole, 6-way
S_{III} = 3-pole, 4-way
S_{IV} = 1-pole, 4-way
S_{k1} = 1-pole, on-off
S_{k2} = 1-pole, 2-way

When the switch S_{I} is in position 4, the pulses from clipper V_4 are fed through the "diode pump" into the capacitor C_{16}, and integration of radioactivity intensity takes place. The full-scale deflexion of the pen recorder for radioactivity measurement is adjusted by R_{73}, R_{74}.

To extend the range of integration, an additional circuit (V_{12}, V_{13}) (switched on by S_{k2}) is used to discharge the capacitor C_{16} automatically when the voltage on the recorder reaches a predetermined value set by potentiometer R_{79}. Then the Smith trigger tube V_{12} switches and gives a positive voltage to the control grid of the tube V_{13}, which is normally in cut-off. The plate current of V_{13} activates the relay R, which closes its contacts r_1 and r_2. The contact r_1 discharges the capacitor C_{16} and the contact r_2 connects the capacitor C_{19} to the control grid of V_{13}, to ensure that relay R is not released before the capacitor C_{16} is discharged completely. When relay R releases (C_{19} is charged negatively), the integration continues from zero. Before starting integration the capacitor C_{16} can be discharged by the switch Sk_1.

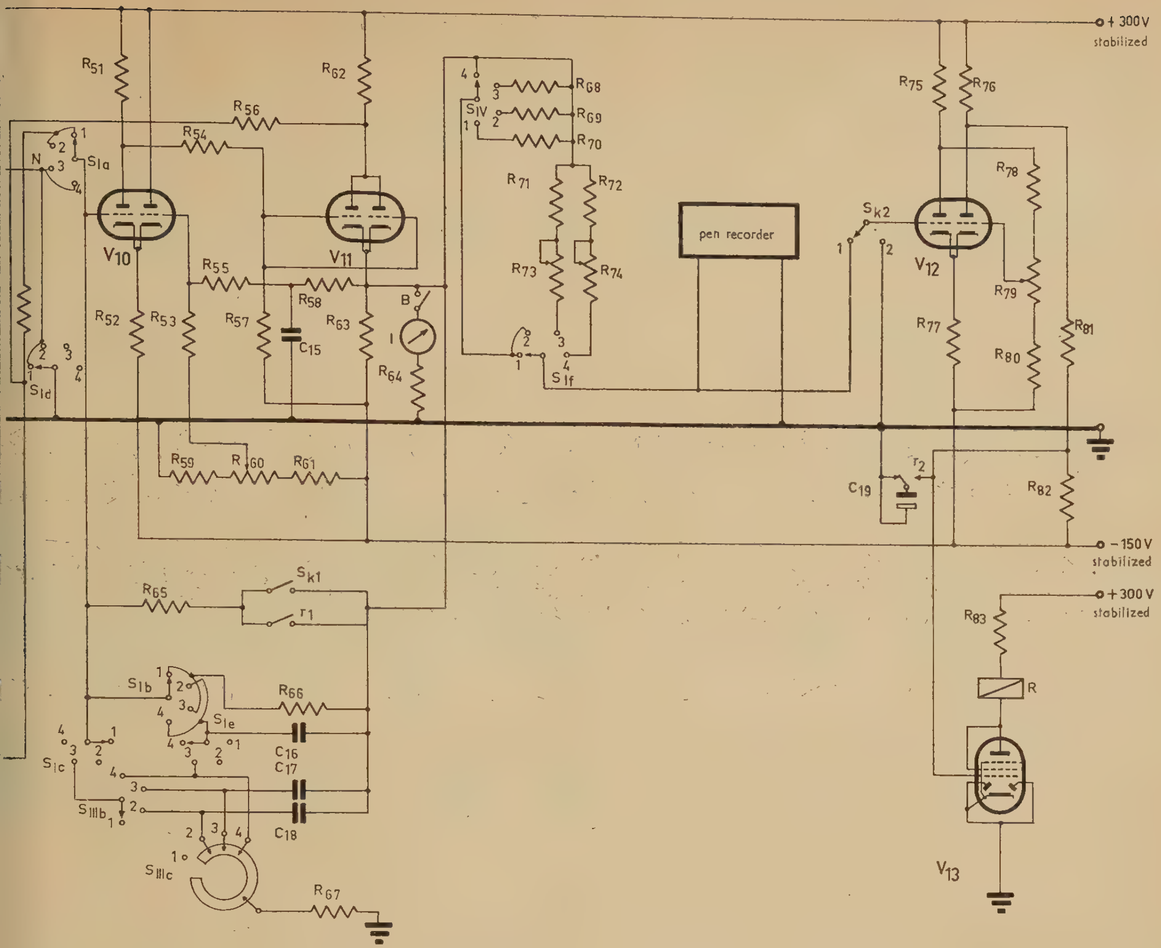
PERFORMANCE OF THE INSTRUMENT

The accuracy of the instrument for photometric measu ments was checked with film specimens of known optic density. The results are shown in Fig. 6. Fig. 7 shows t recording of optical density obtained with film specimens different optical densities [Fig. 7(*a*)] stuck on a paper carri The integration was made with two different sensitiviti [(*c*) and (*d*)]. In Fig. 7(*d*) where greater sensitivity was use the automatic discharging of the integrating capacitor wh full-scale deflexion is reached and the continuation integration from zero can be seen.

By changing the gear sets of the pen recorder it is possib to obtain different scanning speeds. The obtainable spee are: 5, 10, 20, 30, 60 and 120 mm/min.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. M. Konrad for ma useful suggestions and helpful criticism.


+300 V stabilized
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pen recorder
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C19
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Sk1
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SIIIc
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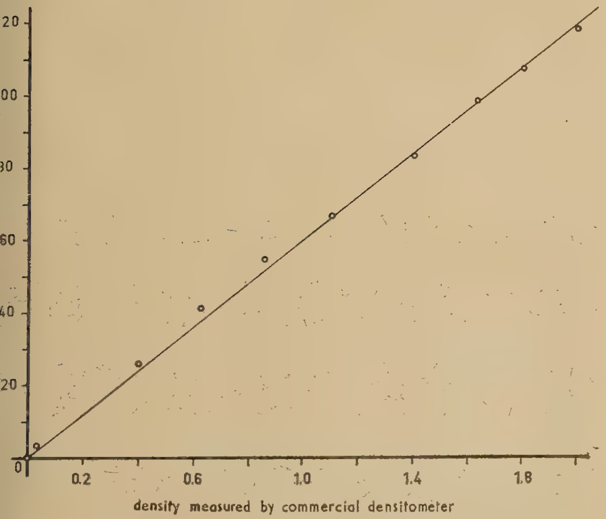
Fig. 5. Circuit diagram of the scanner (*continued*)



ig. 6. Comparison of optical densities measured by a ommercial densitometer and by the described instrument

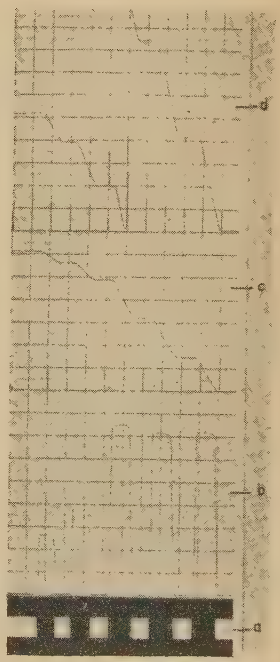
Fig. 7. A sample and its photo-scan

(*a*) Sample made of film specimens of different optical densities stuck on the paper carrier;

(*b*) optical density;

(*c*) integration of optical densities;

(*d*) integration with larger sensitivity.



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Recording projection micrometer

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[*Paper first received* 19 *December*, 1957, *and in final form* 29 *October*, 1958]

This instrument, which may easily be adapted for alternative uses, was designed for making abscissa measurements on microdensitometer curves of X-ray multiplets. It is essentially a printing micrometer in which the curve is positioned by the use of an enlarging optical projection arrangement.

The instrument was designed to facilitate the measurement of salient points on the microdensitometer curves of X-ray multiplets, with respect to known reference lines. The measurement of such points is more satisfactorily made on microdensitometer curves produced using the variable ratio tape coupled microdensitometer(1) than on the original photographs of the spectra. The ordinates of these curves represent the blackening along the spectrum and the abscissae are a function of the wavelengths.

The instrument to be described has been used solely for the above purpose, relieving the fatigue occasioned previously by the use of a simple cursor and vernier scale, and removing the attendant possibility of induced error introduced by this fatigue. It is however clear that it is possible to adapt the instrument to a variety of uses.

The microdensitometer curve on the glass slide *F* (Fig. 1) is placed in the holder *E* and the slide is illuminated by means of the lamp box *K*. An image is produced on the flashed opal glass screen *B* by means of a lens and the mirror *A*. A fine wire immediately behind the screen serves as a fiducial line. Before measurements are made, this wire is set parallel to the grid lines in the projected image (which indicate the ordinate axis of the curve) by means of the eccentric control which moves the upper end of the wire from side to side, the lower end being fixed.

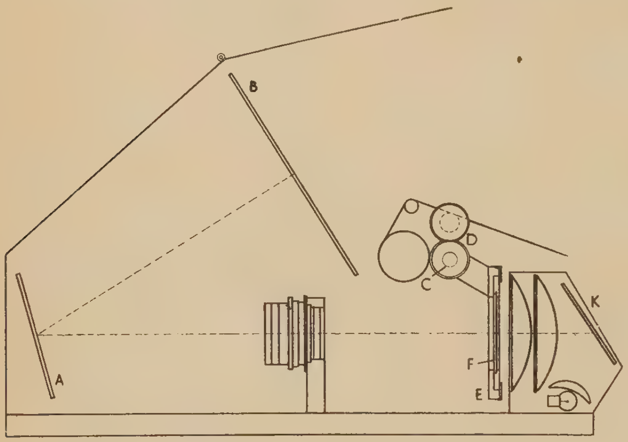

Fig. 1. Sectional view (diagrammatic) of the recording projection micrometer

The holder *E* is driven horizontally in the plane of the slide by means of the lead screw *C* coupled through the two drums *J* (Fig. 2) to a reversible, variable speed d.c. motor, geared down to give lead screw speeds up to 150 rev/min. One of these drums is locked to the lead screw and serves as a hand adjustment. The other is the planet carrier of a differential gear; when this is held stationary by hand, the screw is driven by the motor; when released, the motor runs freely.

The lead screw is connected through the 1 : 1 gears *D* to a revolution counter. This counter has raised type and pa
runs over it and under the roller *G*. A typewriter ribbon r
over the paper. Rotation of the handle *H* moves a set
spring-loaded polythene rollers downwards across the ribb
to record the setting of the counter. A ratchet wheel attac

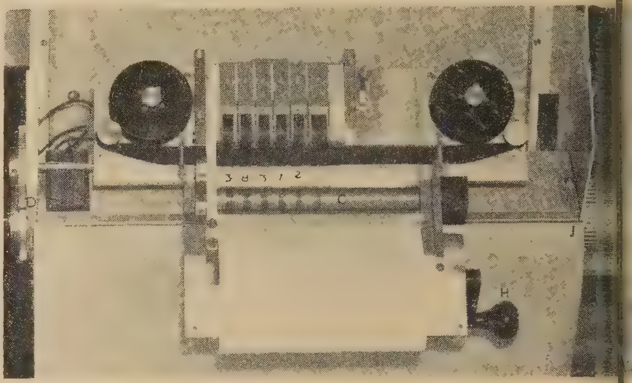

Fig. 2. Detail of the printing mechanism

to *G* is engaged by a pawl on the roller assembly for the re
stroke only, so that the paper is fed forward, ready for t
next printing operation; the rollers are raised clear of t
ribbon during this movement. This device of pressing t
paper on to the type allows the counter mechanism to rema
in position and not to move relative to the lead screw a
gears.

A close-up of the printing mechanism is shown; the figu
visible in the apertures below the ribbon have just be
printed underneath the ribbon and moved down ready for
next printing operation. In this position, details relating
the recorded number may be noted on the paper in the windo
on the right.

The lead screw for this instrument was constructed in t
workshop of this department and has a pitch of $\frac{1}{3}$ mm. O
revolution of the lead screw changes the counter reading
10, so that a change of exactly one unit in the last print
figure corresponds to a slide movement of 1/30 mm. T
fifth and sixth drums of the counter rotate together, the latt
printing a series of divisions, five per digit, from which t
position of the plate on the lead screw can be read to 1/3
mm. A test length equivalent to 1200 digits of the counter w
measured at various places on the lead screw and the resu
were found to vary by the order of 1 digit.

In the particular application of this micrometer to spectru
measurement, the actual displacement of the platehold
corresponding to a change of one digit on the drum
immaterial, as only relative distances need to be known.
desired, it would be possible to adapt the instrument so th
the drum reading would be directly in convenient fractions
a millimetre either by choice of a different pitch for the lea
screw, or by a suitable ratio of coupling gears.

he optical system gives a three times magnified image of microdensitometer trace which adds to the precision of ing on a spectrum detail, but the exact magnification is iously immaterial from the point of view of measurements ıg the plate. It will be noted that all measurements are le under the same optical conditions so that small aberra- ıs in the optics do not affect the measurements. No vision has been made in this instrument for measurements ight angles to the direction of plate movement e.g. relative plitudes of spectrum lines, but this facility could readily be incorporated by means of a millimetre engraved scale on the opal screen from top to bottom alongside the adjustable wire index. Measurements in this direction will be affected by image distortion, but the accuracy required in such measurements is smaller than that of the plate movement.

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Tensile testing machine for microscopic specimens

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The problems of the mechanical testing of whiskers and thin films having gauge lengths down to 0·2 mm and cross-sections as low as 8×10^{-7}mm^2 are discussed. A machine is described which gives load-strain curves for such specimens with minimum load increments of 0·5 mg *f* and with extension readings repeatable to 0·019 μ. A torsion balance applies and measures the load and the strain is obtained by a null method using a marker and a special optical arrangement in a projection microscope. A number of special design features are incorporated to ensure high stability.

1. INTRODUCTION

he bulk state most materials exhibit strengths which are er by orders of magnitude than those predicted from their d energies. However, the same materials in the form of films or small needle crystals known as whiskers often e strengths approaching the theoretical values. This trast provides an insight into the phenomena affecting strength of materials and suggests the need for more ntitative data on the strength of these whiskers and thin s. Although a number of workers have already given h data, the difficult experimental conditions hamper urate measurements. Whiskers of ductile materials only ibit high strengths at diameters less than 2 μ and are ly obtainable in lengths exceeding 2 or 3 mm. Similar rictions apply to measurements on the strength of thin s and special testing techniques must be developed.

everal workers have already described machines which y have used for bend and tensile tests on whiskers. ner(1) used the deflexion of a pendulum to load whiskers obtained the ultimate tensile strengths, but no accurate in values. He reports an accuracy of 1% to 2% for most skers tested. Pearson, Read and Feldmann(2) measured bending force, and deflexion of silicon whiskers at various peratures. They do not discuss the accuracy of their dings, but note the errors which occur in plastic regions bend test. Brenner(3) used a solenoid to apply force to a sker and measured the strains by photographing two cial marks on the whisker between each load increment. estimated the error in strain measurement to be ±0·001 ±0·1% strain. Loads could be applied in the range –20 gf* and he estimated that the overall error in stress asurements was about ±10%. In a later paper(4) Brenner cribes an improved machine in which the solenoid is by a quadrifilar suspension and a differential transner measures the strain. A micrometer-operated brake rrupted the plastic flow when specimens yielded. The llest load increment was now 10 mgf and the smallest extension increment 0·5 μ. Later Brenner(5) quoted a smallest extension increment for the machine of 0·2 μ, while a modification of Brenner's apparatus by Cabrera(6) enabled measurements to be taken to the nearest 0·1 μ. Gyulai(7) used a simpler machine which measured the ultimate tensile strength by employing the calibrated deflexion of a thin cantilever. He had no provision for strain measurement. Of the above instruments, only those based on Brenner's method perform a direct tensile test and measure both the stress and the strain. None of these machines has been used for tests on thin films, but Beams(8) has measured the strength of thin metal films by using the hoop stress set up in a rapidly rotating cylindrical film.

None of these methods appeared suited to our purposes for reasons which are considered below and a careful study was made of our requirements before designing a suitable machine. Several indirect methods, such as vibrational measurements, were considered but did not appear to give the required data simply, so investigations were concentrated on the possible direct methods of mechanical testing. The main possibilities appeared to be the bend test and the direct tensile test. Brenner(3) remarked that in the bend test the stress is complex and non-uniform, both across and along the whiskers. In a bend test on small whiskers the bending load is very small indeed and correspondingly difficult to measure accurately. Moreover, the bend test gives significantly different values for the elastic limit in many cases and data obtained in a direct tensile test are easier to interpret theoretically. For these reasons, it was thought desirable to develop a direct tensile testing machine.

2. CONSIDERATION OF REQUIRED PERFORMANCE

The breaking loads involved in the direct tensile testing of whiskers appear to range from a few milligrams to about 20 g. A tensile testing machine for whiskers should therefore be capable of applying loads in increments of, say, 0·5 mgf up to a maximum load of about 20 gf. The testing of thin films may well involve the application of loads up to about 250 gf so that a machine suitable for testing both whiskers and thin films should cover the force range 0·5 mgf to 250 gf.

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* The symbol gf indicates grammes-force.

Many specimens have an elastic limit of less than 0·1% strain which, on a gauge length of 1 mm, involves an elastic extension of less than 1 μ. If a satisfactory elastic portion of the curve is to be obtained, the extension measurements must be made to an accuracy of at least 0·1 μ. As in many whiskers there is a gradual onset of plasticity a considerably higher accuracy of extension measurements is required for reliable determination of the elastic limit. At the same time, extensions of a millimetre are not uncommon for larger ductile whiskers so that overall extension ranges from about 0·02 μ (200 Å) to about 1 mm may usefully be employed. The ratio of the maximum load to the minimum load increment is thus 500 000 : 1 and the equivalent figure for the extension ranges is 50 000 : 1. These large ranges create special problems of their own as equipment which is suitable for one end of a range is rarely usable through the whole range.

Beside the force and extension ranges needed there are several ancillary requirements. Whiskers of a normal size present especial problems of mounting in a machine for testing. Provision must be made in a machine for assuring the correct alignment of the specimen and care must be taken to see that no stress concentrations occur at the grips. Facilities must be provided for the accurate measurement of the gauge length and, for certain types of whisker which flow plastically at a low stress after reaching a high elastic limit, a strain limiting device must be incorporated to remove the force as soon as plastic flow begins. This enables measurements to be taken on the plastic portion of such curves.

3. CONSIDERATION OF POSSIBLE METHODS

3.1 *Force application devices.* Several force application devices have been considered and some of these are mentioned below. A solenoid can be used to cover a very large range of forces with comparative ease, but for forces at the upper end of the range very large coils or considerable currents would be required, and corresponding thermal effects would be experienced. For accurate work this would involve a constant current power pack and would lead to difficulties with random thermal expansions of the specimen due to convection currents. Another method employs a pendulum with the specimen attached to the bob in a horizontal position. The pendulum support is then moved horizontally, thus deflecting the pendulum from its equilibrium position and applying a known fraction of the weight of the system to the specimen. However, such an apparatus requires a considerable amount of room and poses particular problems of stability. An ordinary laboratory balance might be adapted for use as a force application device but again problems of stability would occur and care would have to be taken to eliminate impulsive loading such as is normally obtained when weights are added to a pan. It would also be very inconvenient to build the rest of a tensile testing machine around such a balance.

A torsion balance was finally chosen as offering the best combination of properties for the purpose. The beam of a torsion balance can be balanced so that it is relatively free from vibrational troubles; wide ranges can be covered by changing the torsion wire used in the system; the apparatus can be contained in a fairly small compass; it can be made mechanically stable and loads may be applied smoothly and continuously to the specimen.

3.2 *Extension measurement devices.* Extension measurement devices, based on inductive or capacitative effects considered but seemed to suffer from zero drift, lack sensitivity or complexity, or were unduly influenced varying external conditions. The use of an optical was rejected to avoid applying excessive forces to the sys through the pivots on which the mirror was mounted. H ever, this objection was later overcome and an optical l forms the basis of a later method. Methods depending optical interference suggest themselves, but stringent ditions must be satisfied to read to 0·1 fringe over an ap ciable range and these cannot easily be met in the force- conditions required by the rest of the instrument. Ra extensions would be impossible to follow by eye and comp automatic counting arrangements would be required. E if a null method is used the departures from the null condit may be very considerable and the same limitations apply.

The method finally adopted depends on direct observat of a marker in the microscope at high power. At first, arrangement appeared to be of limited use, owing to lack of definition of a normal microscopic image, developments of the viewing method enabled high sensiti to be obtained by this technique.

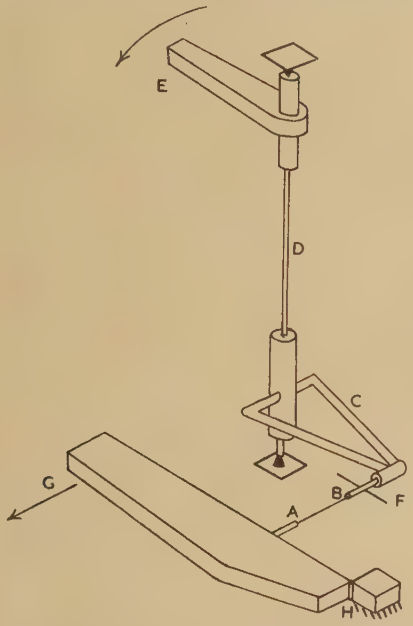
3.3 *Mode of use of measuring elements.* The force extension elements considered above could be applied dire in the conventional manner, but this would limit the rati maximum extension to minimum detectable extension this figure needs to be exceptionally high as discussed Section 2.

A null method has therefore been adopted in which marker is only used as a null detector. The method therefore be very sensitive while a large range of extensi may be covered. As the extension detector is mounte the torsion balance beam the method has the added advanta that the beam is restored to its original position before e reading, so maintaining the correct torsion balance geome

4. DETAILED DESCRIPTION OF MACHINE

4.1 *Summary.* A projection microscope (by Coo Troughton and Simms Ltd.) was chosen for the observati of the marker and the whole machine is designed to fit on the microscope stage. The stage rotation and the two st micrometers are used for specimen alinement and one mic meter is used for gauge length measurement. The machin shown schematically in Fig. 1. The specimen is moun between the grips *A* and *B*, and a load is applied through beam *C* by a torsion wire *D* and torsion head *E*. Extensi of the specimen appears as a movement of the image of glass fibre *F* viewed by a special optical arrangement of microscope, and the null condition is restored by withdrawi the specimen grip *A* using a micrometer at *G* operati through a reduction lever pivoted at *H*. Thus the torsi head micrometer reading is a measure of the force and sensitive micrometer at *G* is a measure of the extension.

4.2 *Torsion balance.* This consists of the torsion he torsion wire, and beam (*E*, *D* and *C* in Fig. 1). The arrang ment of the torsion head is shown clearly in Fig. 2, which a general view of the machine on the microscope. The he is mounted on a platform *J* (Fig. 2) which is joined to base of the machine by a heavy semi-tubular column designed to resist torsion. The lever arm of the head mounted on a rod *L* journalled kinematically between vees and is actuated by a micrometer *M* operating against hardened ball on the arm. By having the ball on the a rather than on the micrometer, the departure from linear of the tangent screw system is reduced. The expression error depends on sin $\theta - \theta$ rather than tan $\theta - \theta$, where the angle between the lever axis and the normal to the rometer axis, and the radius of the ball is ignored. The sion head is arranged to operate for values of θ from ° to +16°. Most measurements involve less than 16° of d rotation and for these the non-linearity is confined to t for ±8° rather than the greater error for 12° which would always be present if the head were to operate between −12° and +12°. The lever arm is retained by one spring which is so placed to provide reactions against the four faces of the vees, a smaller reaction against the micrometer spindle, and very slight tension on the torsion wire to keep it taut.



ig. 1. Schematic diagram of machine, showing torsion alance *E*, *D* and *C*, marker *F*, specimen between *A* and *B*, and lever system *G* and *H*

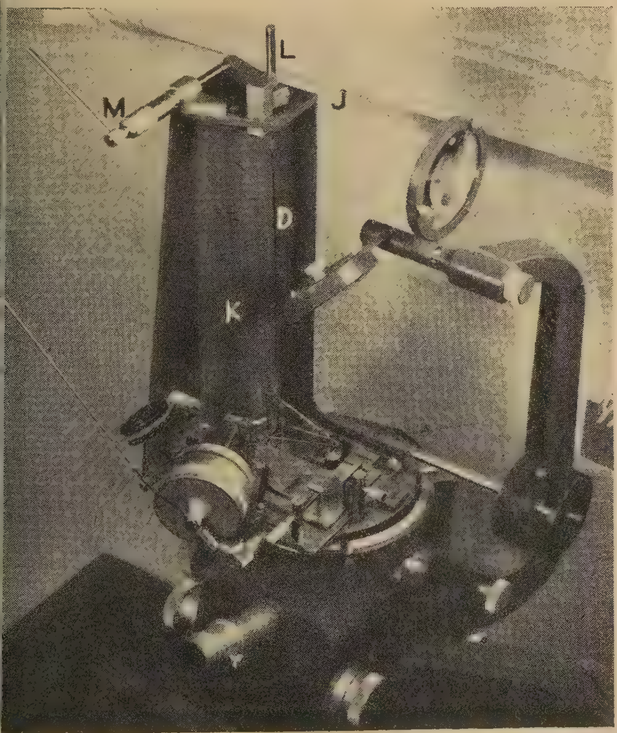


Fig. 2. Tensile testing machine on the stage of the projection microscope

The interchangeable torsion wire *D* is hard soldered into larger diameter end rods which greatly reduce any changes of calibration on its removal and replacement. The finer torsion wires are protected by a tube made of glass so that clearances between the wires and the tube can be checked. The tube protects the wire from mechanical damage and from the thermal effects of draughts. The torsion wires are of silver steel rod and for loads up to 15 gf do not suffer more than 0·075% torsional strain.

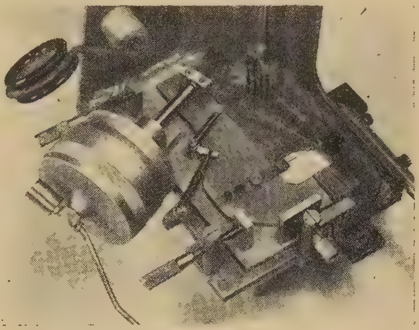


Fig. 3. Details of the lower part of the machine

Fig. 3 shows the lower part of the machine in more detail, and Fig. 4 shows a plan view of the same portion. The beam *C*, Fig. 4, is angled to allow high power objectives and condensers to come close to the specimen and marker through the hole *N* in the base of the machine. It is of hypodermic tubing which gives a strong construction with a low moment of inertia. It is pivoted at *P* on a pair of cross spring pivots having very high stability with absence of friction and backlash. They offer a spring constraint to the system which is immaterial as a null method is employed. Their stability is such that throughout a test the vertical motion of the beam at the far end is not more than 1 or 2 μ. To minimize the moment of inertia of the rotating system, special clamps have been devised for the spring strips in the pivots. A drawing of this system is shown in inset (i) to Fig. 4. Each clamp consists of a rod *Q* and concentric tube *R* with a slight

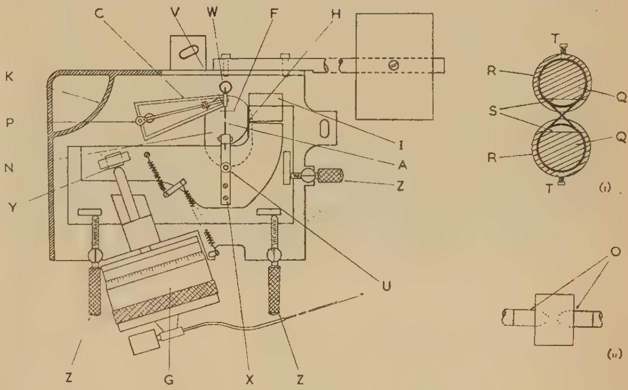


Fig. 4. Drawing of the mechanism excluding the torsion head. Insets: (i) The cross-spring pivot mount; (ii) The film grips

clearance between them. Flats *S* are milled across each clamp and the strips project from these flats and are clamped between the rod and the tube using a clamping screw *T*. This system replaces the more normal right-angled block with clamping pads which would be massive and difficult to incorporate into a tubular beam construction. The complete arrangement is shown in Fig. 3.

A block at the top of the beam at *P* receives the torsion wires in a boss which is co-axial with the cross spring pivot axis, and the specimen grip is mounted in another boss at *V*. A small dash-pot *W* provides damping for the beam. The whisker specimen grips employ electric heating and the two leads to the grip on the beam are provided by the torsion wire and the cross spring pivots. For this purpose, two joints in the beam are glued with Araldite 1 [by CIBA (A.R.L.) Ltd.] to provide insulation and a very small terminal is attached to the top member of the beam.

4.3 *Extension detector.* The 0·001 in. glass fibre marker *F*, Fig. 4, which is used to detect extensions of the specimen is mounted on the specimen grip which projects from the torsion balance, and is viewed in the projection microscope using a 4 mm metallographic objective and two eyepieces in series. A × 6 eyepiece in the normal position and a ×10 eyepiece on an extension tube which replaces the normal screen give a magnification which can be varied between 13 000 and 17 000. The glass fibre acts as a cylindrical lens and may be focused to give a hair line about 5 μ wide. If the condenser is then removed and the lamp iris is practically closed, giving a numerical aperture of 0·04, a series of diffraction lines appear and narrow this central line to a width of 0·5 μ. The field of view is shown in Fig. 5 at a magnification of ×4000. The normal Rayleigh resolution criteria do not apply and successive readings at constant load give a standard deviation of 0·019 μ, using this marker between two graticule lines in a filar micrometer. The low illumination provided at a numerical aperture of 0·04 is compensated by the condenser action of the fibre, and practically eliminates the thermal effects that were found with a normal condenser system.

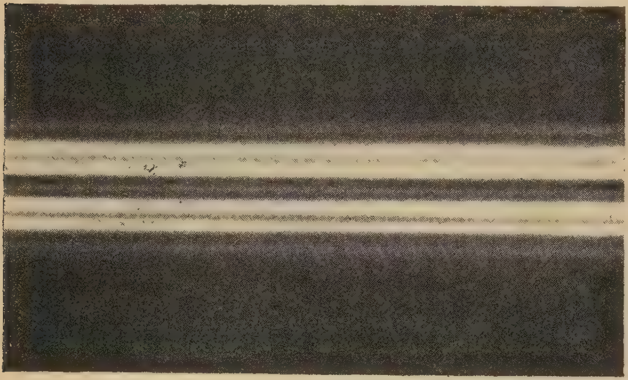


Fig. 5. Appearance of the marker under the normal viewing conditions (reproduced at magnification of ×4000)

4.4 *The lever mechanism.* The micrometer and reduction lever motion is used to withdraw the specimen to restore the null condition of the marker when the specimen extends. The second specimen grip *A*, Fig. 4, is mounted on a phosphor-bronze strip which is attached to the lever at *X*, and is provided with a vertical adjustment screw *U* for specimen alinement and suitable insulation for the leads to the grips. The lever is of considerable width to give stiffness in required direction and is hinged by a single strip flex pivot *H*. A large drum micrometer *G* operates against flat face of a hardened roller *Y* which was inspected in ferometrically for flatness before insertion in the lever. T ensured that negligible systematic errors were introduce the micrometer ball moved over the roller face. Two s balls in the underside of the lever and a spring provide remaining constraints. A viewing lens and vernier provided to facilitate accurate reading of the micrometer.

4.5 *Ancillary services.* The ancillary features to be c sidered are the specimen grips for whiskers and films and provisions for alinement and gauge length measurem For testing whiskers, specimen grips of the type descri by other workers have been used. They consist of e trically heated loops of 0·003 in. tungsten wire, cemen into short stainless steel hypodermic tubes. Fine glass tub is used as an insulator in the tube and a magnesia/sodi silicate mixture forms the cement. Whiskers are moun on these loops using *s*-diphenyl carbazide as a glue. T can be temporarily melted by passing a current and th frozen to secure the whisker. The current is controlled foot switches, leaving both hands free for manipulation the specimens.

It appeared essential when testing thin films to en that the edges of the film were unstressed, as discussed Orowan.(9) Grips to satisfy this condition were obtai by using pointed flat mounts (*O*, inset (ii), Fig. 4). Th concentrated the stress along their centre line and left edges comparatively unstressed. The same glue was u and was melted using an external heater before the film w mounted. Under these loading conditions the useful d are rather more limited than for whisker testing, but strain measurements along the centre line of the grips still significant.

The vertical line on the screen of the microscope was us as a standard reference direction and the stage rotation w locked at an angle such that one stage micrometer w effectively parallel to this line. The machine was provid with a second possible rotation on the micrometer sta about the objective axis and was rotated until the directi of motion of the torsion balance at its zero position coincid with the datum line on the screen. When specimens we mounted they were alined against this datum, thus ensuri axial loading and enabling length measurements to obtained directly using one stage micrometer.

The reduction lever mechanism with its specimen grip mounted on a slide controlled by three screws *Z*, Fig. which enable the alinement and spacing of the grips to adjusted. Additional stability is given to this slide by permanent magnet at *I* fixed to the slide with a small clearan from the steel baseplate.

If required, an adjustable stud could be fitted whi engaged a suitable projection on the torsion balance a removed the load when plastic flow occurred. To obtain balanced load on the stage for easier operation of the sta micrometers the balance weight shown in Fig. 2 was added

5. CALIBRATION AND USE

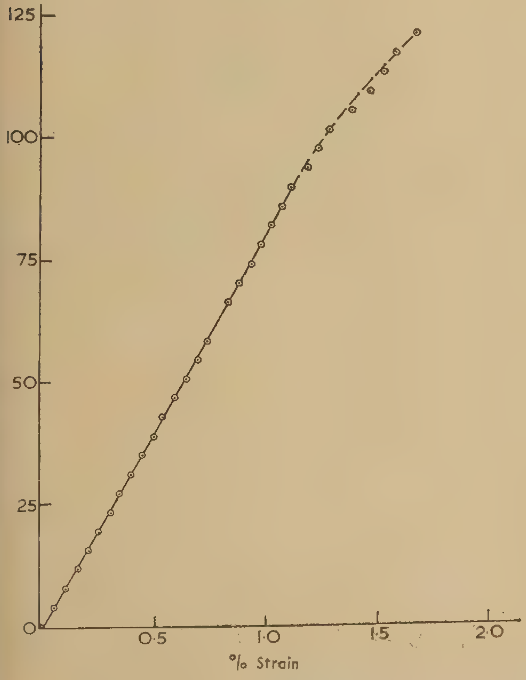
The force constants of the torsion wires were obtained laying the machine on its side and attaching a small weigh scale pan to the whisker grip on the beam. By addi various weights the force constants of the torsion wires we measured. The linearity of the force scales was check io detectable non-linearity could be found. The reduc- lever ratio was found by using the microscope stage ometer to measure the grip movement for a given ement of the drum-micrometer.

e mode of use of the machine may now conveniently be narized. The specimen is offered on a dissecting needle ie grip and is secured at one end in the manner described ction 4.5. By manipulating the slide screws *Z*, Fig. 4, other grip is offered to the free end of the whisker and is similarly secured. The glue on the grips is re-melted, whisker is alined against the datum on the microscope n using a low power objective, and is allowed to assume ess-free position before the glue on the grips is frozen. gauge length is measured and the glass fibre is then ed by the special optical system after the marker has zeroed. Loading begins and readings are taken of and extension as outlined in Section 4.1. A similar nique is used for thin films, but for opaque films incident microscopy must be used. Care must be taken to re that a complete fillet of glue exists round the edge of grips, and the alinement procedure must also be used iminate buckling of the film using incident light micro- y as a sensitive buckling indicator.

the present instance the cross-sectional areas of the imens were obtained from the known value of Young's lulus and the initial slope of the elastic portion of the -strain curve. This method appeared to be necessary onsistent results on microscopic specimens which could be sectioned accurately.

6. PERFORMANCE

iree torsion wires are used to cover the range from ngf to 100 gf in load, and extensions up to 0·8 mm can neasured. When no clamping screws are used to secure nachine to the microscope stage and the microscope is placed on Rubazote pads, the marker appears steady at the viewing magnification of about 15 000. Readings are then repeatable to 0·019 μ. The systematic errors of the extension system should be very small (of the order of 0·5%).



g. 6. Stress-strain curve obtained for 2·5 μ gold film (total elastic extension of 4·2 μ)

The systematic errors of the torsion balance are less than 1% at the worst, but no figures are available for any random errors. However, measurement on a complete stress-strain curve showed total errors equivalent to extension measurement errors of 0·026 μ. This figure included all random movements of the various mechanisms, such as the slide adjustment screws, and including the random error of the extension measurement system, so the error attributable to the torsion balance is very small.

Specimens having gauge lengths as low as 0·28 mm have been tested and a complete stress-strain curve having thirteen points has been obtained for a potassium chloride whisker which had a breaking load of 15·6 mgf on a cross-sectional area of 0·87 μ^2 and a total extension to failure of 1·61 μ on a gauge length of 0·35 mm. Films down to 0·2 μ have been tested on gauge lengths of about 0·3 mm. A stress-strain curve obtained for a 2·5 μ gold film is shown in Fig. 6. The gauge length was 0·35 mm and so the total elastic extension represented is 4·2 μ.

7. CONCLUSION

A machine capable of measurements of considerable accuracy over wide ranges has been described. It was developed originally for the testing of whiskers but was later adapted to thin film work. Similar machines might well prove useful for a wider range of applications such as the testing of fibres or thin filaments. At the present time a similar machine is being developed to attain higher accuracies, to allow measurements to be made at various temperatures, and to cover wider ranges without the use of a projection microscope.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. C. C. Evans who shared much of the development work, and Mr. J. E. Gordon for his encouragement of the project. He is indebted to Mr. R. W. Gooding, Mr. A. W. A. Rushton and certain staff of the Cambridge Instrument Company for their helpful suggestions and assistance. The paper is published by permission of the Chairman of Tube Investments Limited.

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Linear voltage temperature furnace for thermal analysis

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[*Paper first received* 26 *June, and in final form* 30 *September*, 1958]

A furnace is described which may be operated in a vacuum or an inert atmosphere, and which was developed for thermal analysis studies of beryllium and its alloys. Extremely rapid heating and cooling rates may be employed if required, or, with slow heating and cooling rates, a linear variation in voltage with time will produce a correspondingly near-linear variation in temperature. This is of great value in thermal analysis work, and is very much cheaper than the electronic controllers or mechanical cam devices that are usually necessary.

CONSTRUCTION

Diagrams of the furnace are shown in Figs. 1 and 2. The heating element is a 9 in. long, $1\frac{1}{4}$ in. diameter tube, made by forming a 0·002/0·003 in. thick tantalum sheet to a cylinder, and riveting the two edges of the sheet together along their length. Current is led to the ends of the element *via* two half-cylindrical, 0·020 in. thick sheets of tungsten, which surround the tube as shown in Fig. 1(*b*), and which thereby act not only as current leads, but also as an inner radiation shield. The tube element is a sliding fit in two tungsten rings, one at each end of the tube, each ring being tightly riveted to one of the half-cylinders. Molybdenum connectors, screwed to the opposite end of each half-cylinder, bolt on to vertical copper rods which act as current leads and supports for the whole furnace assembly. The entire furnace, with the exception of the copper lead-in assembly, is surrounded by six concentric radiation shields, formed from 0·010 in. thick molybdenum sheet. To facilitate rapid assembly and dismantling, the shields have been made as two half-cylindrical sets, riveted together with spacers between the sheets, and supported from one side of furnace. Upon removing these the furnace proper can inspected. Further heat insulation is provided by radia shields at the top and bottom of the furnace. The comp furnace is 14 in. high and 4 in. in diameter. Throug central hole in the lower set of shields, a vertical stai steel tube extends into the furnace zone, and supports nickel reference block and beryllia crucible used in ther analysis experiments, as shown in Fig. 1(*a*). A length alumina tube situated between the reference block and steel support, serves as an insulator to prevent the ra dissipation of heat from the furnace. By extending the st tube downwards through an O-ring seal in the base pla the reference block and crucible can be raised or lowe during operation, so that they may be positioned in a z of uniform temperature. To even out more fully temperature fluctuations a pyrophyllite tube is positio inside the tantalum heating element, completely covering crucible assembly, and small circular radiation shields ins the furnace tube, above and below this assembly, serve lengthen the zone of uniform temperature. Since the furna is only required to operate up to about 1330° C in its pres

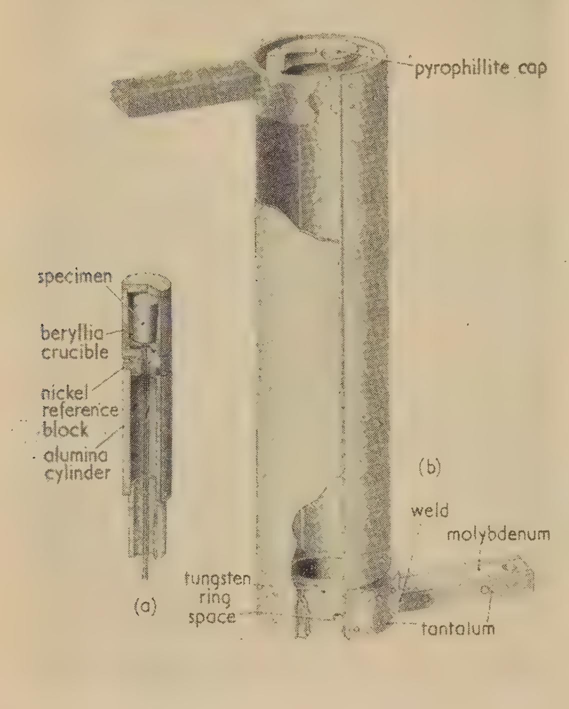
pyrophillite cap
specimen
beryllia crucible
nickel reference block
alumina cylinder
(a)
tungsten ring space
(b)
weld
molybdenum
tantalum

Fig. 1. (*a*) Crucible and reference block. (*b*) Current lead-in assembly (without inner furnace tube)

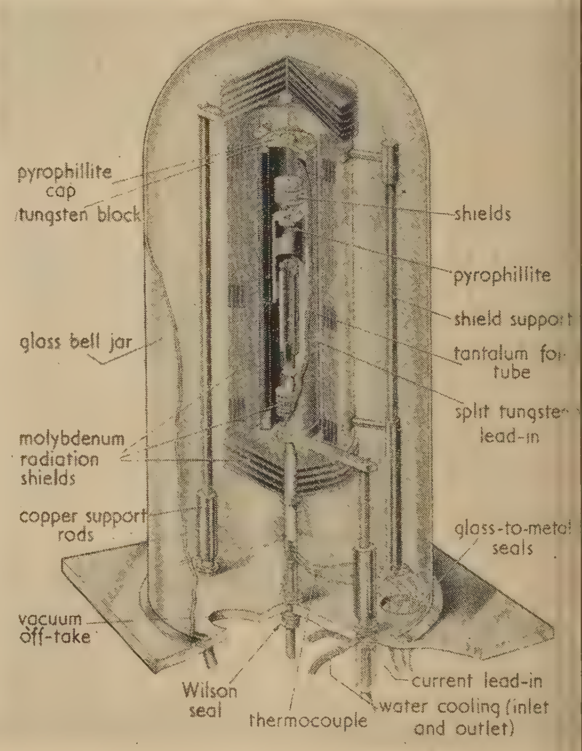
pyrophillite cap
tungsten block
shields
pyrophillite
shield suppo
glass bell jar
tantalum fu tube
split tungste lead-in
molybdenum radiation shields
copper support rods
glass-to-metal seals
vacuum off-take
Wilson seal
thermocouple
current lead-in
water cooling (inlet and outlet)

Fig. 2. Thermal analysis furnace

loy, the use of pyrophyllite and stainless steel as furnace rials is possible. Pyrophyllite was chosen as a refractory use of its availability and machining properties. It is a e efficient heat insulator than the metallic sheath which ld have to replace it for operation to higher temperatures. temperature variation over a 1½ in. length in the centre ie furnace is about 1·0° C at 600° C, increasing to 2·5° C 200° C, as measured by three thermocouples on the ible and reference block, which pass down inside the iina and steel tubes and thence to tubular metal-to-glass on the base plate.

ie entire furnace assembly is enclosed by a glass bell jar ı. in diameter and 24 in. high, which is evacuated by a diameter oil diffusion pump backed by a rotary pump. ultimate vacuum attainable with this system is better 1 × 10^{-4} mm of mercury at 1000° C.

FURNACE OPERATION

ıbular furnaces of this type usually suffer from poor act resistance at one end of the element, since here a ion fit must be provided to allow for the expansion and raction of the tube as the temperature is raised and ered. Poor contact resistance inevitably leads to local -heating and puncturing of the tube. This type of re has been largely overcome with the present design :

) the linear expansion of the two semi-cylindrical tungsten leads to the tube is roughly the same as that of the tantalum element. The coefficient of linear expansion of tungsten, near room temperature, is $4{\cdot}3 \times 10^{-6}$ in. in.$^{-1}$ °C^{-1}, compared with $6{\cdot}5 \times 10^{-6}$ in. in.$^{-1}$ °C^{-1} for tantalum. The tungsten expands over an 18 in. length (one tungsten lead is held at the bottom and expands upwards, the other, held at the top, extends downwards), whereas the tantalum tube expands over a 9 in. length only, but runs at a much higher temperature than the surrounding tungsten shield. This arrangement minimizes the longitudinal movement of the element in its mountings;

) both ends of the tantalum tube are reinforced with a strip of 0·010 in. thick tantalum sheet which lends rigidity to the element where it meets the tungsten ring, and serves to maintain contact between the two metals. Since the tantalum tube diameter expands more than the bore of the tungsten rings, increasing the temperature actually improves the contact.

xperience with the furnace over the past three years has cated that eventual failure of the element is more often to oxidation embrittlement of the element as a whole to bad contact resistance at the ends of the tube. The age life of an element extends over several months, and thirty to forty temperature cycles up to 1300° C may arried out in this time. A replacement tube can be made fitted in about three hours.

ower for the furnace is provided by a 6 V, 250 A transner, which is run at its maximum rated output for ation at 1300° C. To attain temperatures in the region 330° C the transformer is overloaded by not more than of its rated capacity. When used for thermal analysis 6 V transformer is preceded by a variable output mains sformer, and a mains voltage stabilizer. An induction of variable transformer is used which permits a true inuous variation of the output voltage; with the alternamoving brush type of transformer some stepwise alteration in voltage is inevitable. Such a stepwise variation, however small, has been found to result in a corresponding temperature variation within the furnace, which can seriously affect the sensitivity of thermal analysis experiments. With a suitably geared motor drive the voltage may be reduced or increased continuously: in the present experiment the speeds have been such that heating and cooling rates of 2–5° C/min have been maintained between room temperature and 1300° C. With such slow rates it has been found that the rate of increase and decrease of temperature with time remains practically constant over the whole range. This may well be a consequence of using a pure metal such as tantalum as a heating element, since the very high temperature coefficient of resistance of tantalum results in a nearly linear relationship between voltage input and power output compared with the (voltage)^2 relationship found in furnaces employing conventional resistance elements such as Nichrome. A considerable amount of heat loss occurs, however, by conduction and radiation, and these factors too must play their part in determining the furnace characteristics. Convection plays a small part in heat transfer, since there is no significant

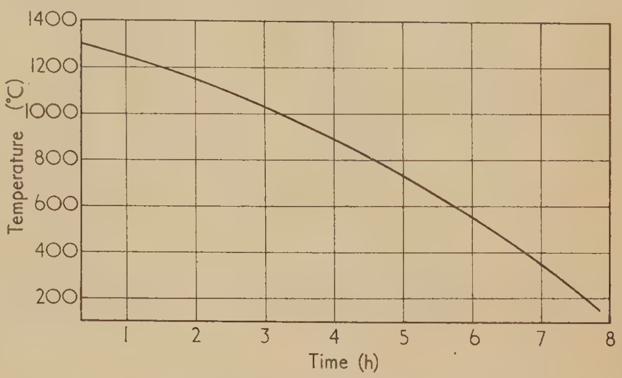

Fig. 3. Cooling curve for the furnace obtained using a geared motor

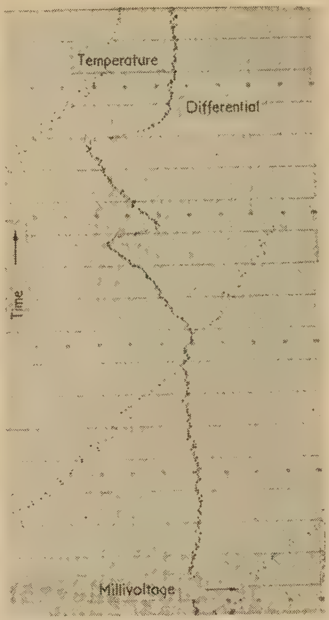

Fig. 4. Portion of a typical heating curve for beryllium, showing melting point arrests

difference in the voltage-temperature relationship when operating in vacuum, or under half an atmosphere of argon.

The linear time/voltage/temperature characteristic of this furnace is of great value in thermal analysis work where linear increase of temperature with time is essential. Normally this necessitates complicated cam arrangements connected to the variable transformer,* or even more complicated and costly electronic equipment.† With the present furnace design all that is required is a direct motor drive to a varia transformer.

A typical time/temperature cooling curve for the furnac shown in Fig. 3, which was obtained using a geared m to the input Variac; and a typical differential thermal anal plot obtained with a 4 g sample of beryllium, showing double arrest at the melting point, is given in Fig. 4.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the help and guida given them by Mr. G. C. Ellis, and Mr. W. B. H. L during the design and experimental stages.

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Liénard phase plane integraph

By R. Butler, M.Sc., Ph.D., A.Inst.P., The Manchester College of Science and Technology

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A mechanical linkage is suggested for obtaining trajectories, corresponding to damped oscillations, in the Liénard plane. Its construction is based on the Henrici–Coradi instruments, although, as a second order differential equation is being analysed here, the mechanism is more intricate.

THEORY

The differential equation $\ddot{x} + f(\dot{x}) + n^2x = k$, where n and k are constants, is reducible to the form

$$\ddot{x} + g(\dot{x}) + n = o \qquad (1)$$

by suitable linear changes in dependent and independent variables. This equation is insolvable formally except for special damping functions, but permits of geometric treatment in the construction of velocity-displacement phase plane trajectories using the method given by Liénard.⁽¹⁾ The differential equation is written in the form

$$d\dot{x}/dx = -[g(\dot{x}) + x]/\dot{x} \qquad (2)$$

and in the $(x, \dot{x})$ plane is constructed the curve AB (see Fig. 1) defined by $x = -g(\dot{x})$ which will generally pass through the origin, lying in the second or fourth quadrants for damped motion. Suppose now that, in the construction of a particular phase curve, the point P has been reached. Then the gradient at P is given by equation (2), which may be interpreted geometrically as follows. Construct the right triangle PNM, when the required direction is at right angles to P For

$$\text{slope at } P = -\tan\angle NMP = -NP/NM$$
$$= (QN - PQ)/NM = [-g(\dot{x}) - x]$$

which is equation (2). In practice several hundred small s ments are drawn, each requiring the construction of a rig triangle like PNM, and the method is tedious, though sim and, with care, accurate.

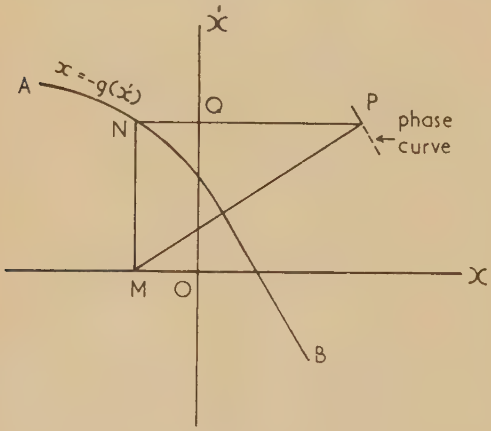

Fig. 1. The Liénard construction

THE INTEGRAPH

One stage of the Liénard construction is so simple that o expects it to be capable of mechanization. One point, ho ever, needs consideration. In the segment by segme method the construction starts from P, i.e. the generated cur determines the course of the construction and not AB. any mechanism it is clearly desirable to reverse this procedu and merely move a pointer along AB letting a pen at P dra out the phase curve. It then becomes necessary to ensu that P always moves at right angles to PM. Otherwi mechanization reduces to the provision of variable leng members to represent NP, PM, MN.

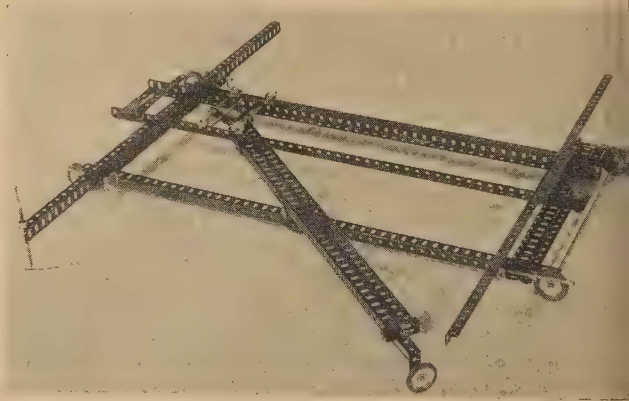

Fig. 2. Model of mechanism

Meccano model of a possible mechanism has been made is shown in Figs. 2 and 3. The construction has been d on the integrating mechanisms of Henrici(2) and Coradi ect to the limitations of available standard parts. Motion e Ox direction, which is common to both input and out-curves, is provided by the main carriage *abcd* rolling on

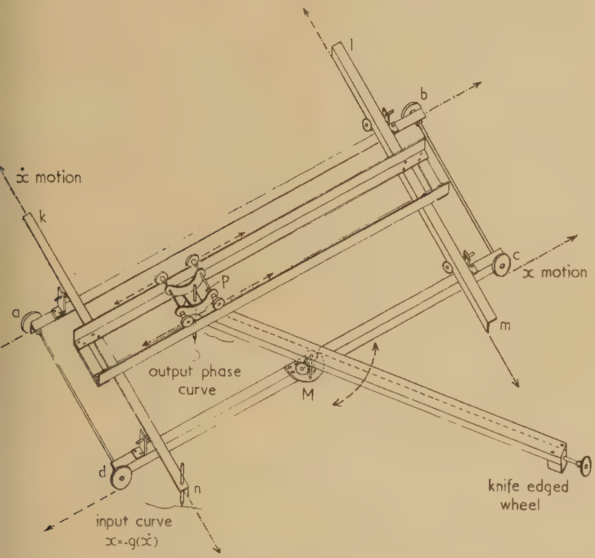

Fig. 3. Mechanism shown diagrammatically

els at its corners. An upper carriage *klmn* can move ss the lower one by means of rails and grooved pulleys to ide $O\dot{x}$ motion. A third motion to the left and right on is achieved similarly, the centre of this carriage corre-ding to the point P. M is a roller and swivel bearing to *abcd* and the variable length member PM is free to te at P and both turn and roll at M. As it is not necessary to use the same origin for both input and output curves the pointer N for following the input curve OA may be attached anywhere to *klmn* and an extremity (n in the figures) is convenient. To ensure that P moves at right angles to PM a knife-edged wheel is attached either at P or somewhere on PM or PM produced. If the wheel is at P itself then the output may be recorded by letting the wheel trace its path through carbon paper, but otherwise a pen or pencil is located at P. It is the presence of this wheel that accounts for the term "integraph" for equation (2) is essentially a first order differential equation which is being integrated, the knife-edged wheel acting as an Adbank-Abakanowicz integrator.

As the tracing point at n follows the input curve the carriages *abcd* and *klmn* are both being moved. P, already moving in the $O\dot{x}$ direction in virtue of the motion of *klmn*, assumes a further component in the $O\dot{x}$ direction according to its traverse of *klmn* which is determined by the required variation of PM under the influence of the integrating wheel. In the model friction limits the range of accurate operation to around where PM is at 45° to $O\dot{x}$ but, judging from the performance of the Henrici-Coradi instruments, the introduction of needle or ball bearings throughout would mean that the mechanism would function accurately over practically a whole cycle, the limit being when the direction of motion of the knife-edged wheel approached $O\dot{x}$.

A simple test for the instrument is to take AB coinciding with $O\dot{x}$ when P generates a circle.

ACKNOWLEDGEMENT

I am indebted to my colleague Mr. S. V. Fagg for help in the construction of the Meccano model.

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Analogue computer for the solution of product integrals

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The computer will accept up to three input variables simultaneously; they are presented in the form of recorder chart traces which are traversed mechanically, but are followed by hand. The instantaneous product of the input variables, or of some pre-selected function of them, is formed and charted. Mechanical integrators compute the integrals of each of the input variables and of the product. The particular arrangement described computes $\int ab\sqrt{c}dt$, $\int adt$, $\int bdt$ and $\int \sqrt{c}dt$ where $a(t)$, $b(t)$ and $c(t)$ are the input variables.

any branches of physics and engineering the need arises valuate the integral of the product of two or more ables. The usual set-up for this problem on a differential yser(1) makes use of the relationship

$$\int a(t)b(t)dt = \int a(t)d[\int b(t)dt]$$

consists of an arrangement for the output of the $b(t)$ rator to provide the integrating variable for the $a(t)$ rator. This technique has been employed in special-ose computers, such as a product integraph described by er and Clarke(2) and a mechanical autocorrelator ribed by Seiwell.(3)

An alternative approach is first to form the product of the variables in a multiplier and then to integrate the multiplier output. Whilst this may appear a more obvious technique than the two-integrator arrangement, it may not always be simpler in terms of the components required. Product integration by this method is one of the operations performed by Middleton's curve computer(4) and by the curve analyser of French and others.(5)

The present need to solve problems of this type arose in the course of work in the Fuel Research Station's Calorimeter Building,(6) which is equipped for the performance of a variety of measurements on heating appliances. Smoke emission from an appliance is assessed from the optical density D of the smoke in the chimney and the flow rate F_g

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* Now at Royal Aircraft Establishment, Farnborough.

of the flue gas at the optical measuring point. The instantaneous rate of smoke emission is proportional to DF_g, and the total emission in a test period to $\int DF_g dt$. The optical density, measured by a servo-balancing double-beam equipment,(7) is recorded linearly. The flue-gas flow rate is obtained from the measurement at room temperature of the flow rate of air entering the appliance, multiplied by a factor proportional to the absolute temperature T_g of the flue gas; the air-flow rate is measured by an orifice which gives a record of pressure differential p proportional to the square of flow rate. The total smoke emission is proportional therefore to $\int D\sqrt{p}T_g dt$. The variations occurring in the recorded quantities are such that no "short-cut" solution is acceptable, and it has been necessary to employ the laborious method of multiplying individual readings, re-plotting, and using a planimeter to obtain the area under the curve.

In addition to the smoke calculations, thermal measurements in the calorimeter rooms require several calculations of the changes of heat content of the air which passes through the room to the appliance and leaves as flue gas. These involve an integral of the form $\int F(T_1 - T_2)dt$, or $\int \sqrt{p}(T_1 - T_2)dt$ as the flow rate is recorded as an orifice pressure differential. Whilst this calculation may be simplified if $(T_1 - T_2)$ remains approximately constant, as occurs for some types of test, there are many cases where such simplification is not possible and a laborious calculation is necessary.

When a computer for these problems was being designed it was considered that for the smoke emission calculation it would be an advantage to obtain a plot of the product before integration, as this would illustrate variations in the smoke emission during the test period. For heat content calculations it was not considered necessary to plot $F(T_1 - T_2)$ directly and it was therefore decided to treat each integral as the difference of two, $\int FT_1 dt - \int FT_2 dt$, except where the temperature difference was recorded directly by a differential thermocouple, thus avoiding the need for a subtraction in the computer.

The requirement for a plotted product necessitated the use of the multiplier and integrator arrangement rather than the two-integrator system. The multiplier was required handle a two-term or a three-term product, and in each one of the terms would be the square root of the recor variable. The mechanical design of the computer shoul such that it would conveniently operate with the recor instruments already installed in the Calorimeter Building

PRINCIPLES OF OPERATION

It was decided from the outset that the computer sho obtain its input from the chart traces produced by the exis recording instruments. Any system for obtaining information directly while the tests were in progress wo have entailed modifications to fifteen instruments and wo have required several multipliers. The possibility of u automatic curve-following was considered to be impractic because several of the recorders were multi-line instrum giving six or twelve records as discontinuous stamped m ings. It was necessary, therefore, to provide for man following of two or three charts simultaneously, the c movements being synchronized and preferably adjustable speed so as to give the best conditions for following pe or smooth curves.

The computer was planned to consists of separate chart tables for each of the recorder charts, an output table on which the product curve would be automat drawn and integrated and a central unit containing multiplier and the chart-drive control. An arrangeme this type, having only non-rigid cable connexions bet the units, would provide the maximum flexibility in la and would permit the later addition of further input tables to handle different types of recorder chart.

The method adopted for driving the charts in synchron was to use a single motor to drive four magslip transmi each linked to a magslip receiver in one of the chart ta The motor was to be continuously adjustable for speed permit chart-speed variation whilst retaining synchroni Each table would contain the necessary gearing for conve the magslip output to a speed suitable for the partic chart on that table; the gear ratio might be different on

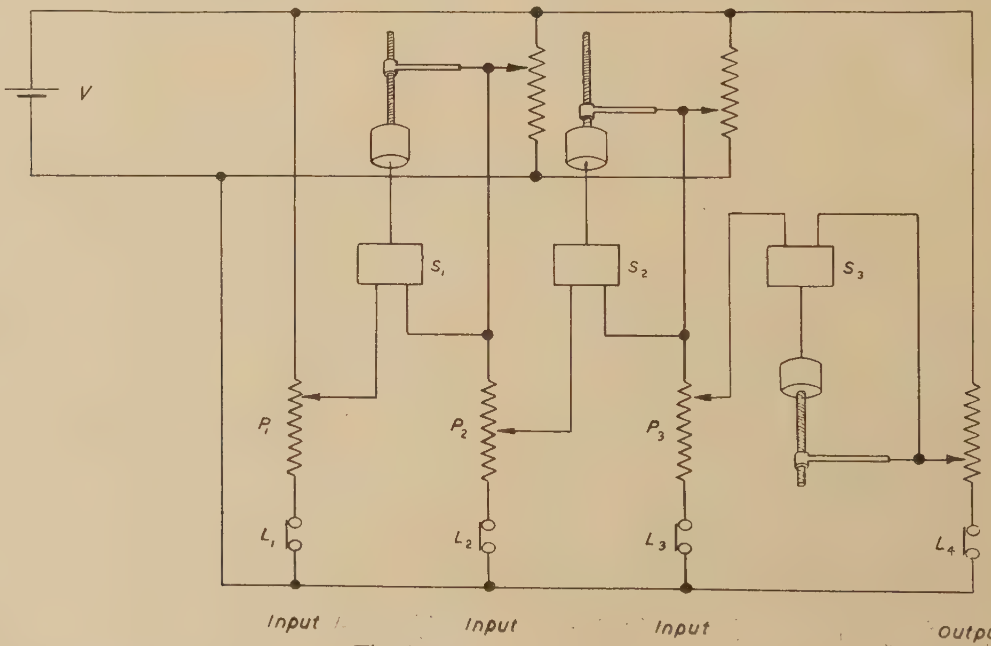

Fig. 1. Circuit of multiplier

ous tables, depending on the various chart speeds oyed in the recorders.

ne accuracy envisaged for the multiplier was of the r 0·5% of full scale, which was comparable with the racy of the recorders. It was considered that a servo-ated electrical multiplier would conveniently and omically fulfil this requirement. The circuit adopted is vn in Fig. 1.

ne precision linear potentiometers P_1, P_2 and P_3 are nted in the input tables, each being arranged so that its ing contact is operated by the curve-following cursor; s a similar potentiometer in the output table, connected he curve-drawing pen. Suppose the input variables, essed as a fraction of full scale, are a, b and c. Then e the battery voltage V is applied directly to P_1, the ed output from this potentiometer is aV. This output age is applied across P_2 without loading P_1 by means of servo-mechanism S_1, which automatically taps the correct age from R_1. The tapped output from P_2 is then abV, by a similar process that from P_3 is $abcV$. The product is indicated by the pen on the output table, because the ery voltage V is applied directly across P_4 and the moving act is driven by servo-mechanism S_3 to a position corre-nding to $abcV$.

Vhen one term of the product is the square root of the rded variable, a mechanical square-root linkage can be d between the cursor and the potentiometer contact. provide an effective zero below the base line of the recorder t (as when an input temperature is required in degrees olute), a resistance of suitable value can be inserted in es with the corresponding potentiometer in place of the rting link L_1, L_2 or L_3. A resistance inserted in place of would serve to expand the effective scale for a product wing relatively small variations about a large mean value. his multiplier can be used for two-term or three-term ducts, and could be extended for more terms if desired. s slightly different from the servo-multiplier described by oka(8) and by Korn and Korn(9) because the voltage-erating potentiometers are used in the multiplying circuit, i.e. the primary inputs are shaft rotations rather than voltages. It has the advantage that a stabilized voltage supply is not required because the output indicator operates from the same supply as the multiplying potentiometers.

To integrate the product curve it was decided to use a wheel-and-disk mechanical integrator, fitted in the output table, so that the disk was driven by the chart-drive magslip and the position of the integrating wheel was controlled by the curve-drawing pen, i.e. by the value of the product. This arrangement was extended to the input tables as well, because average values of the input variables are often required and to obtain these during the product-integral evaluation would save a separate operation with a planimeter.

DETAILS OF DESIGN AND CONSTRUCTION

Input chart tables. The general construction of an input chart table is shown in Fig. 2. The main framework comprises two aluminium alloy end plates or frames and a centre plate, mounted on a rigid aluminium alloy base plate and connected by a series of tie rods and spacers. At the front of the right-hand compartment is a roller, with a friction brake, on to which the chart to be read is wound by means of the knob which projects through the right side frame. The chart passes over a guide bar and then over the drive roller, to which it is held by spring-loaded idler rolls, before passing out through an opening at the rear of the table. The chart is thus made to move parallel to the observation window in the right-hand hinged cover.

At the rear of the table are a fixed guide rod and a lead screw, each with its axis parallel to that of the drive roller; they pass through both compartments of the table and the lead screw is operated through gearing by means of a handwheel at the right of the table. In the right-hand compartment a block, mounted on the guide rail and driven by the lead screw, carries a hinged cursor engraved with concentric circles, and visible through the window in the cover. Thus, as the chart is driven past the window, the cursor can be made to follow the trace by manipulation of the handwheel,

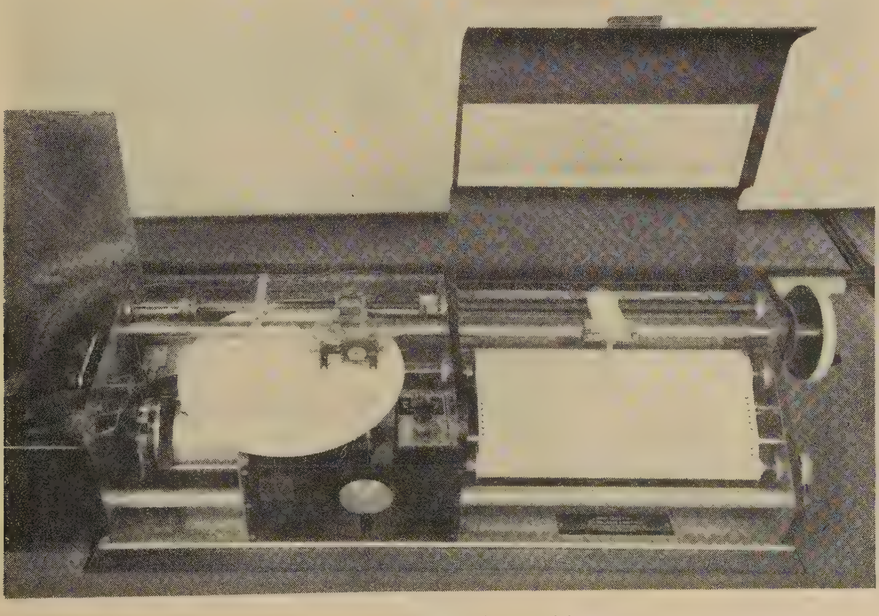

Fig. 2. Input chart table

the position of the lead screw being proportional to the instantaneous value read off at any moment.

At the end remote from the handwheel, the lead screw carries a worm which engages with a worm wheel attached to the spindle of a precision potentiometer, supported from the left side frame. By this means the rotation of the lead screw is converted into an output voltage.

In the left-hand compartment a second block, also mounted on the guide rail and driven by the lead screw, carries a planimeter head of conventional design. The head is mounted on coned pivots and is driven along the radius of a large paper-covered light alloy disk by means of the lead screw. The pitches of the portions of the lead screw in the left- and right-hand compartments are chosen so that traversing the cursor from zero to full scale causes the integrator wheel of the planimeter head to traverse in step, from the centre of the disk to the outer edge.

Both the disk and the drive roller are themselves driven by a magslip receiver through a gearbox contained in the left-hand compartment. Thus the planimeter head integrates the input function with respect to chart traverse and so with respect to time.

Various adjustments are provided; both the cursor and the planimeter head can be moved laterally, by means of screws, for adjustment to zero. The two portions of the lead screw are connected by means of a collet-type clamp which allows one to be rotated with respect to the other. This can be used for adjustment to zero and, in addition, allows the integrator zero to be raised or depressed with respect to the chart zero. The body of the precision potentiometer can be rotated, again for zero adjustment. The drive roller has a ratchet mechanism to facilitate the insertion the chart. The gearbox incorporates a pair of spur gea which are readily accessible, and which are chosen from standard, commercially available series, so as to facilitat change of ratio. By choosing suitable ratios, charts record at different speeds can be dealt with simultaneously. Simi change wheels allow the ratio of gearing between the han wheel and lead screw to be varied to suit the chart spe and the wishes of the operator. Finally a handwheel provided, at the front of the left-hand compartment, means of which the chart and the disk can be set. Wh pressed in, this handwheel engages a bevel drive to the ma slip shaft and operates a switch isolating the magslip fro its associated transmitter.

Three of the input chart tables have conventional, consta pitch lead screws and differ only in details associated w the charts which they are designed to accept. Thus t roller diameter, roller width and pin spacing vary necessary.

The fourth input table is the one which contains the squa root linkage referred to above. In this table the right-ha portion of the lead screw has a thread with a square l pitch, as shown in Fig. 3, instead of the constant pitch sc of the orthodox tables. Thus the number of turns of the le screw required to traverse the cursor from zero to a gi value on the chart is proportional to the square root of th value. Hence the integrator head and the potentiome movements are proportional to the square root of the inp value. The lead screw was produced by end milling accordance with a set of co-ordinates calculated in advan and was then smoothed off by hand. A similar techniq

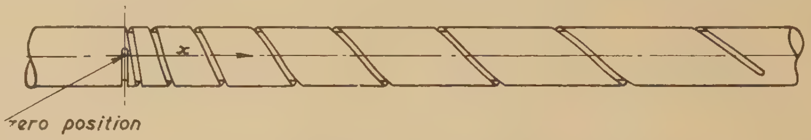

Fig. 3. Lead screw with square law thread

Groove cut according to the law $x = 0 \cdot 1n^2$, where x is the distance along the axis from zero position and n is the number of turns.

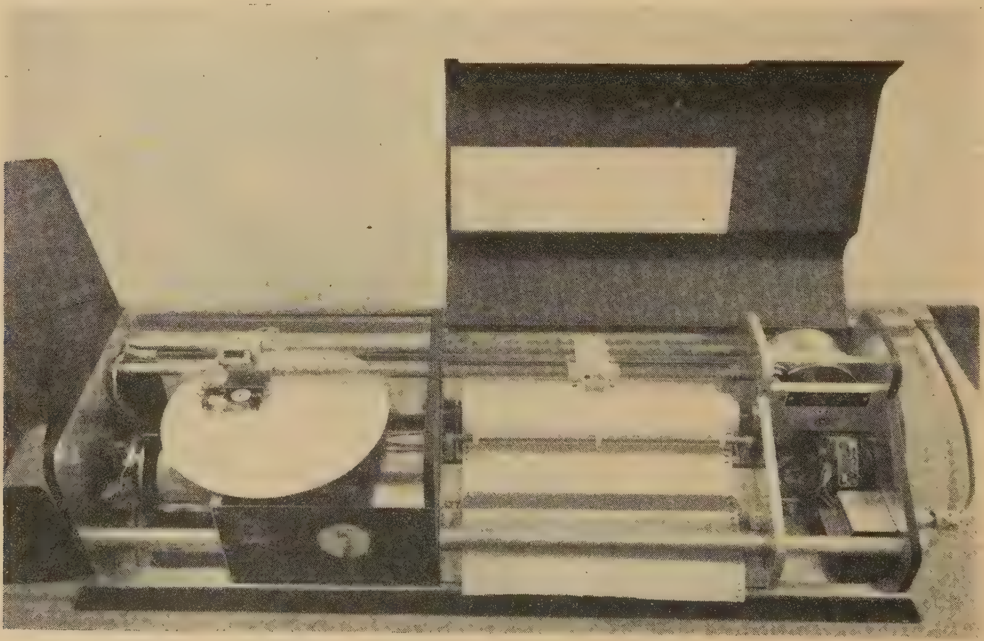

Fig. 4. Output chart table

d be used to produce other screw forms, e.g. a sine or
law thread.

ll the tables have hinged covers over the left- and right-
d compartments with windows to allow the integrator
chart to be seen. Internal lighting is provided to
itate chart following and reading of the integrator.

utput chart table. The general construction of the out-
chart table is shown in Fig. 4. The main framework
sists of four aluminium alloy plates or frames, mounted
a rigid aluminium alloy base plate and connected by a
es of tie rods and spacers. The centre compartment
ains the chart assembly. Once again there is a special
t roller with a friction brake, a drive roller with spring-
led idlers to ensure proper chart contact and an exit
e. But here the chart roller is at the rear of the table
the chart moves forward over the drive roller, where it
be seen through the window of the right-hand cover,
re emerging at the front of the table.

he left-hand compartment contains the magslip receiver,
ch again provides the main drive, and the gearbox
ciated with it. As in the input tables, the gearbox
vides drives for both the drive roller and the integrator
which is mounted with its axis vertical on top of the
box assembly. But the direction of rotation of the
slip, and hence of the drive roller and of the disk, is
rsed.

Two guide rails which pass through both the left-hand and the centre compartments are fixed near the top of the table with their axes parallel to the drive roller. Two blocks are arranged to slide on these guide rails, one in the left-hand compartment and one in the centre compartment. The former carries a conventional planimeter head arranged in a similar manner to that in an input table, and sliding on the integrator disk. The latter carries a recorder pen consisting of a syphon of "hypodermic" tubing dipping into a reservoir of ink.

In the right-hand compartment a precision potentiometer is mounted with its axis perpendicular to the guide rails. Its spindle carries a pair of pulleys around which are wires fixed to the two sliding blocks described above; idler pulleys fixed to the left-hand frame complete the system. The diameters of the drive pulleys are chosen such that a full-scale rotation of the potentiometer spindle causes the pen to traverse from zero to full-scale deflexion on the chart and the planimeter wheel from the centre to the edge of the disk. The chart zero on the output table is, of course, on the right-hand side of the drive roller viewed from the front. Thus if the potentiometer contact is rotated to give a voltage equal to the instantaneous product of the input variables, the product is recorded on the chart and the integral with respect to chart traverse, and therefore with respect to time, is obtained from the integrator mechanism. Such a rotation is obtained

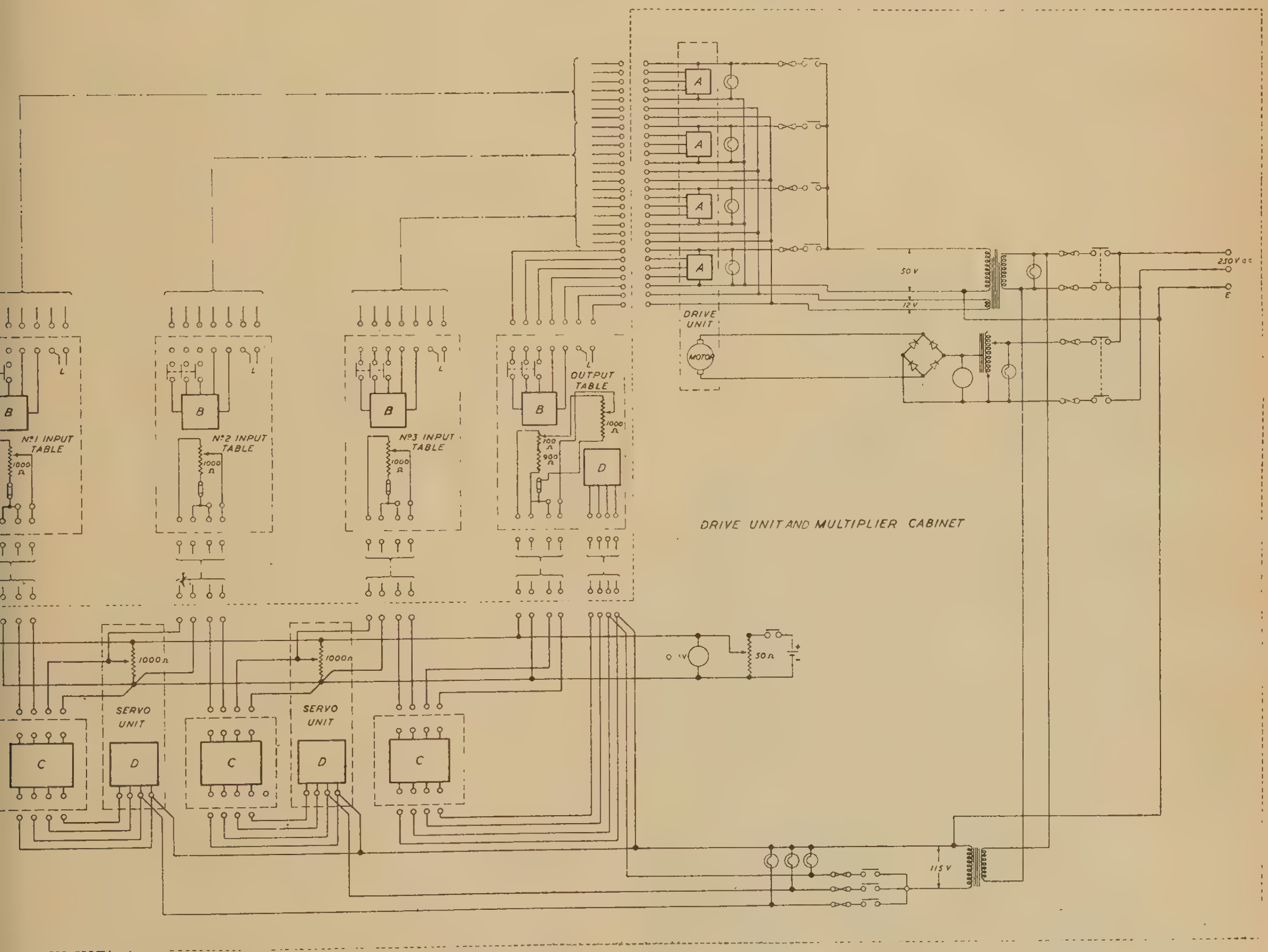

Fig. 5. Circuit diagram of computer

A, magslip transmitter; *B*, magslip receiver; *C*, standard servo-amplifier (as used in electronic potentiometric recorders); *D*, servo-mechanism; *L*, table lighting circuits.

by driving the potentiometer shaft from a servo-motor, mounted in the right-hand compartment, through suitable gearing.

Various adjustments are again provided. Both the pen and integrator head can be adjusted to zero by means of the screws which connect the wires to the blocks. These also serve to apply tension to the wires. The disk and drive roller can again be set by means of a handwheel on the front of the left-hand compartment, which is pushed in to engage bevel gears on the magslip shaft, and to operate the magslip isolating switch. As in the input tables the overall drive ratio can be altered by change gears. A similar pair of gears, projecting through the right side frame, are included in the gear train between the servo-motor and the potentiometer shaft. The potentiometer body can be rotated for zero setting and an auxiliary pre-set potentiometer is provided to control the voltage across the precision potentiometer. Finally, the drive roller again has a ratchet to facilitate insertion of the chart.

Hinged covers are provided for both the left-hand and the remaining compartments and these contain windows to allow the integrator and pen to be observed during operation. Built-in lighting facilitates these observations.

Multiplier and drive unit. A detailed circuit diagram of the multiplier and drive unit, together with the input tables, is shown in Fig. 5. The auto-transformer, which provides a chart speed control, does not form an integral part of the unit, but is placed near the operator who is most likely to wish to vary the speed.

Interconnexion and disposition of units. The chart tables are connected to the multiplier and drive unit by multiway cables; separate screened cables are used for the power leads and the computing voltage leads.

The general layout of the computer is shown in Fig. 6. The control panel can be seen on the trolley-mounted multiplier and drive unit. The output chart table is on the end desk and three input tables, including one with square-r
linkage, on the side desks; the fourth input table, which c
be connected in place of one of the others, was under co
struction at the time.

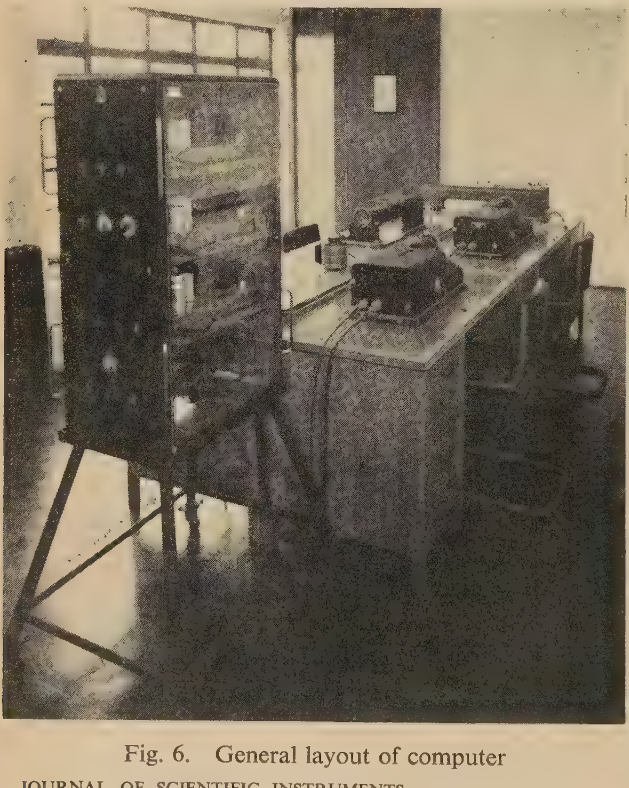

Fig. 6. General layout of computer

PERFORMANCE

Accuracy. The accuracy envisaged for the multiplier w
of the order 0·5% of full scale. With this in mind,
precision potentiometers chosen were of 0·1% lineari
backlash in the mechanical drives was kept to a minimu
and the supply voltage to the multiplier circuit was ma
large enough (about 1 V) to ensure that any dead-zone eff
on the servo-mechanisms was insignificant.

Each chart table was examined for linearity and backla
by accurate measurement of the potentiometer outp
voltage and the integrator reading corresponding to vario
positions of the cursor (or pen) across the chart. Deviatio
of the output voltage tended to be in multiples of 0·13
(approximately) of full scale; this quantity corresponded
the distance between windings on the potentiometer whi
although it was of 0·1% linearity, was not utilized over
full length in a chart table. On the output table the deviatio
from linearity were mainly either 0·00 ± 0·02 or 0·13
0·02%; the backlash was either 0·00 ± 0·01 or 0·13
0·01%. On two of the input tables (including the squa
root table) the maximum deviation was 0·26 ± 0·02% a
the maximum backlash 0·13 ± 0·01%. On the third inp
table the maximum deviation was 0·34% and the maxim
backlash 0·27%; it was apparent that its mechanical dri
was not quite as good as that of the other tables, giving
greater backlash, but it was also found that the division
the recorder chart on which it operated were not perfec
spaced, and this contributed to the deviation from lineari

Integrator readings, taken over a length of chart corr
sponding to one revolution of the integrator disk, showed
maximum deviation for any table of 0·35% of full scale a
a maximum backlash of 0·28%. Thus 0·35% of full sca
is the maximum error detected on the potentiometer outp
or integrator for linearity deviation or backlash on any tab

The accuracy of the multiplier circuit was checked by setti
the second and third input tables (in Fig. 1) at full scale an
then adjusting the cursor on the first table to various positio
across the chart and comparing the indication produced
the output table. This procedure ensured that all the serv
mechanisms were operated when the cursor position w
changed, but ignored any non-linearity errors introduced
the second and third tables. With the servo-amplifie
adjusted to optimum sensitivity, the maximum divergen
detected between the first input and the output tables w
0·2% of full scale; at most points it was zero or 0·1%.

It may be concluded from these observations that t
desired order of accuracy is obtainable for any reasona
length of chart traces; multiplication at an individual poi
might show a greater error than 0·5% if all the compone
errors happen to be cumulative.

Speed. When used in the recorder for which they we
designed, the servo-amplifier and motor systems are capab
of driving into balance across the full width of a 10 in. cha
in 1 s. This speed is preserved for the servo-mechanisms
and S_2 (Fig. 1) which have only to drive a potentiomet
contact. Servo-mechanism S_3 has to drive the pen a
integrator blocks of the output table in addition; after adjus
ing the gear ratio between the motor and the block drive
give the highest speed, time for full-scale traverse is 3·2
This is the overall full-scale response time for the multiplie

ppears to be quite adequate for manual curve-following the chart speeds employed.

he motor and magslip chart-drive system is capable of ng a maximum speed of 7½ in./min with one chart table nected and 6½ in./min with four tables. These speeds are siderably in excess of what would be used for tracking a ve showing average fluctuations. The speed controller es a smooth adjustment from zero to maximum speed, ng effective over the top six-tenths of its full travel.

CONCLUSION

This product-integral computer is capable of performing calculations for which it was designed with an accuracy 0·5% of full scale or better.

The performance obtained in practice depends on the chart ed used, in relation to the slope of the curves, and on the ll of the operators. It is apparent from the short period experience available that sufficient skill is fairly rapidly ained, and that adequate accuracy is then obtainable at a sonable chart speed. For instance, a six-hour test recorded 2 in./h with curves of moderate slope might be tracked at out 3 in./min, giving a computer time of about 4 min.

The input tables available were designed for:

(i) 10 in. charts from Micromax recorders (by Integra) and Speedomax-G recorders (by Leeds and Northrup).
(ii) 10 in. charts from Multelec recorders (by G. Kent, Ltd.).
iii) 10 in. charts from Wide-Strip recorders (by Ether).
iv) 6 in. charts from Arkon pressure recorders (by Walker Crosweller) (with square-root linkage).

her types of 10 in. chart could be accommodated by fitting uitable drive roller, and other types of non-linear linkage could be provided by the same technique as used here for the square-root linkage.

ACKNOWLEDGEMENTS

The authors desire to acknowledge the contribution made by Mr. P. E. Jones of the Fuel Research Station drawing office in the mechanical design of the computer.

The work described in this paper formed part of the programme of the Fuel Research Board of the Department of Scientific and Industrial Research and the paper is published by permission of Mr. S. H. Clarke, then Director of Fuel Research. The illustrations are Crown copyright and are published by permission of the Controller, H.M. Stationery Office.

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Apparatus for the measurement of specific heat of metals

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[*Paper received* 4 *September*, 1958]

An apparatus is described which enables the measurement of the specific heat of metals to be made *in vacuo* up to a temperature of at least 500° C.

The specimen in the form of a flat cylinder has its temperature steadily increased by a metered amount of electrical energy supplied by an internal heater. Radiative heat losses are eliminated by means of an adiabatic screen which surrounds the specimen and which is maintained at the same temperature. The rate of temperature rise can be controlled by the energy input enabling specific heat to be investigated over small temperature ranges. An accuracy of within ± 3% has been obtained at temperatures up to 500° C.

INTRODUCTION

r the calculation of thermal transients occuring in a actor, due, for example, to changes in power level, a owledge of the specific heat of the materials involved is quired. An adiabatic calorimeter similar to that described Armstrong,(1) has been constructed for measurements on me fuel and canning materials.

In this method the temperature of the specimen is increased supplying a known amount of electrical energy, while loss heat is reduced by a guard system surrounding the specimen d maintained at the same temperature. The specimen is two similar halves, providing a symmetrical arrangement ound the internal heater and also ease of heater assembly. e specimen size is 12 cm^3, so the method allows specific heat determinations to be made on materials which are only available in small amounts.

DESCRIPTION OF THE APPARATUS

The general assembly of the apparatus is shown in Fig. 1, and details of the specimen in Figs. 2 to 4. The latter consists of two cylindrical sections, which enclose a heater consisting of a coiled coil of 34 s.w.g. platinum–rhodium wire, of resistance about 40 Ω, wound on a mica former (Fig. 3).

The specimen sections are electrically insulated from each other by means of a mica annulus. The heater leads pass through small holes, and the ends are peened into light saw-cuts in the outer surface (Fig. 4). Current and potential leads of 25 s.w.g. copper are also attached to each half of the specimen. To reduce conductive heat loss along the copper heater leads a short length of platinum–rhodium wire (of much lower thermal conductivity than copper) is inserted in each lead. To avoid radiative heat loss from the heater wire through the mica annulus a lip is machined on each half of the specimen as shown in Fig. 4. The specimen is supported by three alumina tubes and is surrounded by a copper guard system, which consists of three parts, the top and bottom disks and the cylindrical side. Each part has an independent heater of Nichrome wire (Fig. 4).

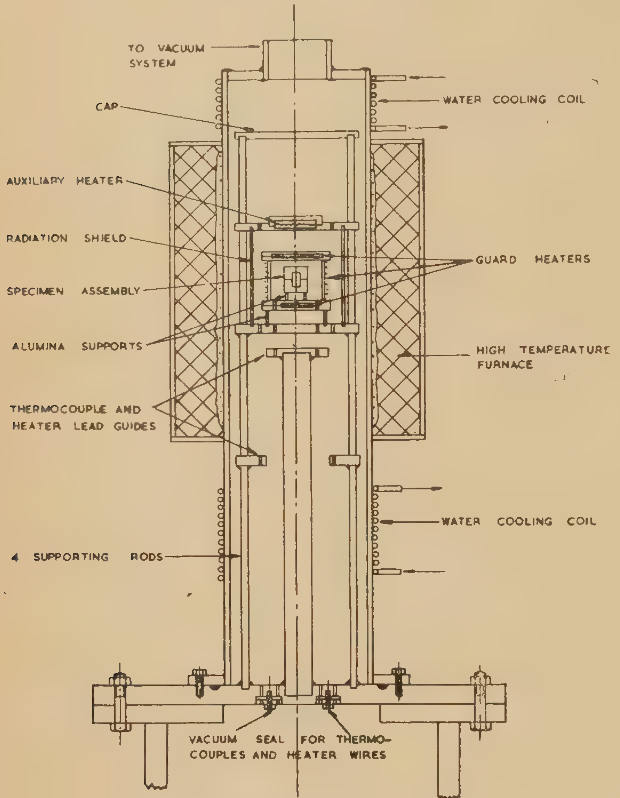
TO VACUUM SYSTEM
CAP
WATER COOLING COIL
AUXILIARY HEATER
RADIATION SHIELD
GUARD HEATERS
SPECIMEN ASSEMBLY
ALUMINA SUPPORTS
HIGH TEMPERATURE FURNACE
THERMOCOUPLE AND HEATER LEAD GUIDES
WATER COOLING COIL
4 SUPPORTING RODS
VACUUM SEAL FOR THERMOCOUPLES AND HEATER WIRES

Fig. 1. General assembly of specific heat apparatus

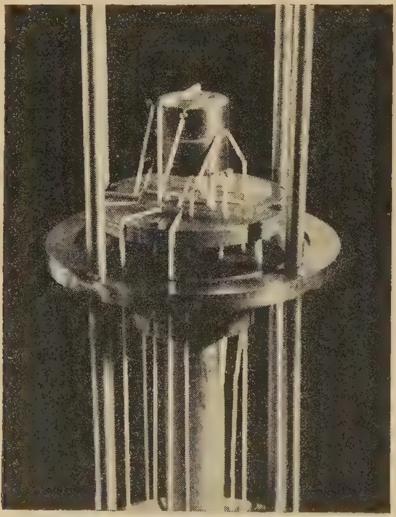

Fig. 2. Specimen assembly

Thermocouples of 34 s.w.g. platinum/platinum–13% rh dium wire are peened in the specimen top, side and botto Opposite these, similar couples are peened in the guards order to indicate differences between specimen and gua temperatures. The thermocouples are connected *via* an i junction and a multi-position switch to a precision verni potentiometer, and the six temperatures are read in successi continuously throughout a determination.

The whole specimen and guard assembly is enclosed in evacuable steel tube on which is wound a Nichrome heat

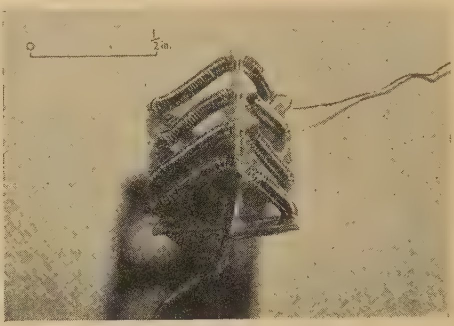

Fig. 3. Specimen heater

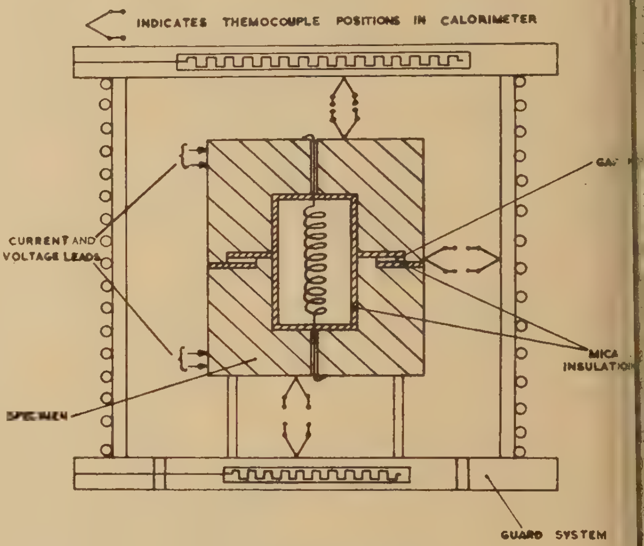
INDICATES THEMOCOUPLE POSITIONS IN CALORIMETER
GA
CURRENT AND VOLTAGE LEADS
MICA INSULATIO
SPECIMEN
GUARD SYSTEM

Fig. 4. Specimen assembly

to enable determinations to be carried out over a range o temperatures up to a maximum of 900° C. The temperatur at the furnace wall is controlled to within about ±3° C b means of a mechanical controller-recorder and a mercur relay. A vacuum of better than 0·05 μ of mercury is maintained in the system in order to prevent oxidation of th specimen and heat loss by conduction or convection Thermocouple and heater leads are brought through compressed rubber ring, vacuum-tight seal.(2)

OPERATION OF THE EQUIPMENT

The apparatus has been used to measure the mean specifi heat of materials over 50° C temperature intervals up to a maximum temperature of about 400° C. The temperature range covered for each result can be shortened if required without appreciably affecting the accuracy.

For a specific heat determination, current is passed through specimen heater for a known time, during which cor-onding couples on specimen and guard are matched by isting guard heater currents. The current through and voltage across the specimen heater are measured to hin ±½%. Time is measured to an accuracy of better 1 3 s in 20 min, which is approximately the duration of a ermination.

. second guard system and supporting assembly has been structed, in order that whilst the specific heat of one cimen is determined, another specimen may be assembled. s has proved valuable when a series of determinations is and.

THEORY

he amount of heat q required to increase the temperature mass m by $\Delta\theta$ is given by

$$q = ms\Delta\theta \qquad (1)$$

ere s is specific heat.

 this heat is provided electrically in time t,

$$q = EIt/J = ms\Delta\theta \qquad (2)$$

ere E = voltage
I = current
J = mechanical equivalent of heat.

ome of the heat supplied may be (a) absorbed by material e to the specimen, or (b) lost by conduction along leads ched to the specimen.

quation (2) may be re-written

$$q = EIt/J = ms\Delta\theta + \Sigma(m's'\Delta\theta') + \Sigma\left(\frac{KA\theta}{l}\cdot t\right) \qquad (3)$$

ere $\Sigma(m's'\Delta\theta)$ represents the summation of effect (a) and $\left.\frac{KA\theta}{l}\cdot t\right)$ the summation of conduction losses (b) by ous paths of conductivity K, cross-sectional area A and mal gradient θ/l.

 will be observed that the magnitude of (b) may be found measuring the rate of supply of energy necessary to ntain the system at constant temperature. Loss (a) may 1 be determined by varying the mass m and extrapolating $m = 0$. Alternatively, if a measurement is carried out 1 a material of known specific heat, the overall value of h error terms for particular temperature conditions may obtained.

he error terms may be considered as an error in the value pecific heat. Equation (3) then gives

$$q = m(s + \Delta s)\Delta\theta$$

ere $$\Delta s = \frac{1}{m\Delta\theta}\left[\Sigma(m's'\Delta\theta') + \Sigma\left(\frac{KA\theta}{l}\cdot t\right)\right] \qquad (4)$$

It will be observed that the error Δs will be reduced by increase of mass m, though in the recent programme shortage of test material limited specimen dimensions to 1 in. diameter × 1 in. long. Further, the product $m\Delta s$ is not dependent on the specimen, and in the calibration of the equipment this term was obtained as a function of temperature for a standard material.

CALIBRATIONS

In the calibration of the equipment approximately 50° C temperature ranges have been covered for each result, with a maximum temperature of 400° C.

The material chosen as standard in the determination of the correction term Δs was "Steel No. 19" obtained from the National Physical Laboratory and details of this material are given together with the results in Table 1. The difference in

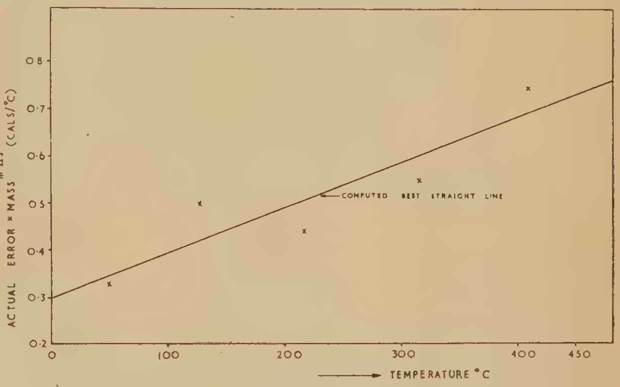

Fig. 5. Error times mass of specimen against temperature for N.P.L. steel No. 19

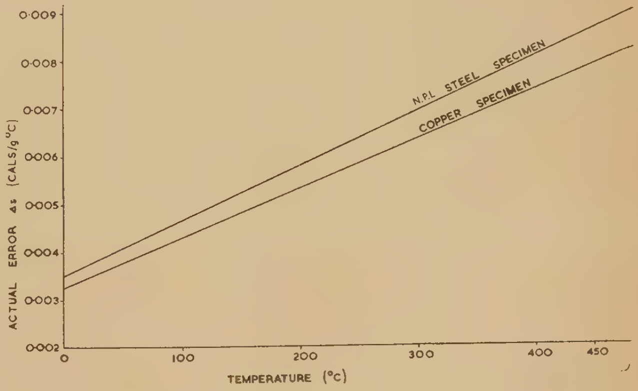

Fig. 6. Actual error curves computed from Fig. 5

Table 1. *N.P.L. alloy steel No. 19*

lysis

C	Si	Mn	S	P	Cr	Ni	Mo	Cu	Al	As	
0·315	0·20	0·69	0·036	0·039	1·09	0·073	0·012	0·066	0·005	0·028	%

Annealed at 860° C. Density = 7·842 g/cm³ at 15° C.
Specimen weight = 84·52 g.

mperature (°C)	*Measured specific heat* S_M	*N.P.L. value* S_N	ΔS_M $(=S_M-S_N)$	$m.\Delta S_M$	Δs *(from best line—Fig. 6)*	*Corrected specific heat* S	*Scatter* $S - S_N$
50	0·1193	0·1154	0·0039	0·328	0·0040	0·1153	−0·0001
127	0·1282	0·1223	0·0059	0·498	0·0050	0·1232	+0·0009
217	0·1337	0·1285	0·0052	0·440	0·0060	0·1277	−0·0008
316	0·1425	0·1360	0·0065	0·548	0·0071	0·1354	−0·0006
409	0·1553	0·1465	0·0088	0·743	0·0082	0·1471	+0·0006

specific heat between the results obtained in the calibration and those read from the N.P.L. curve (Fig. 7) were then calculated. These differences were multiplied by the specimen mass and plotted against temperature (Fig. 5). The equation of the best straight line through these points was calculated, thus giving a correction-temperature relation which is independent of the specimen. From this line, the error Δs can be obtained for any material by dividing the correction at the specified temperature by the specimen mass. This has been done for steel as shown in Fig. 6. The scatter in these corrected results can be seen in Table 1 and is shown in Fig. 7 where these results are plotted on the curve supplied by N.P.L.

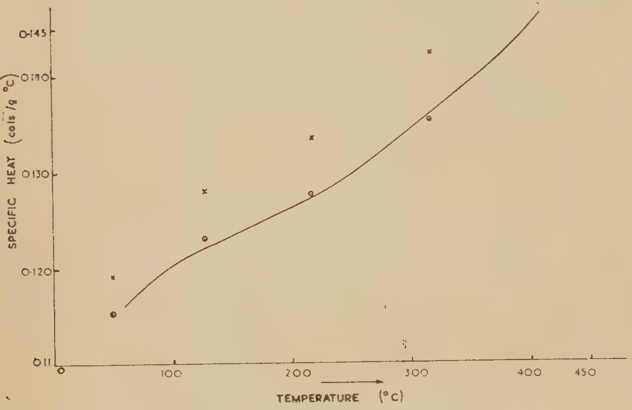

Fig. 7. Specific heat of N.P.L. steel No. 19

⊙ = corrected results.
× = uncorrected results.

In order to confirm the method, a run has also been made on a commercial copper specimen. The results were corrected by the above method (Fig. 6) and are given in Table 2 and Fig. 8, where they are compared with results obtained for copper by other authors.

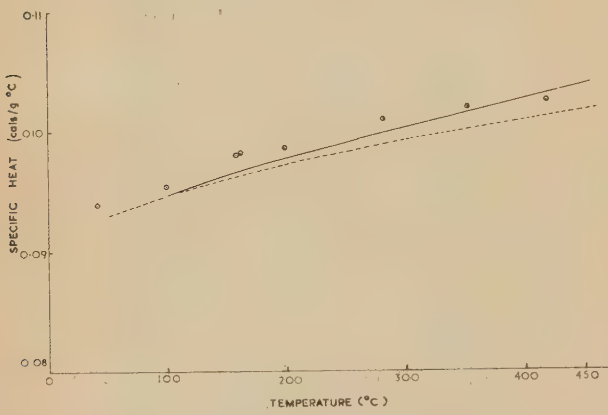

Fig. 8. Specific heat of commercial copper

Full line indicates Klinkhardt's results.(4)
Dotted line indicates Bronson's results.(5)
⊙ = corrected Culcheth results.

Table 2. *Commercial grade copper*

Temperature (°C)	*Measured specific heat*	Δs (*from Fig.* 6)	*Corrected specific heat*
42	0·0976	0·0037	0·0939
100	0·0993	0·0043	0·0954
158	0·1029	0·0049	0·0980
162	0·1031	0·0049	0·0982
199	0·1039	0·0053	0·0986
282	0·1072	0·0062	0·1010
353	0·1090	0·0070	0·1020
419	0·1103	0·0077	0·1026

Results obtained by other observers are given in Fig. 8.
Specimen weight = 91·15 g.

DISCUSSION

The correction for heat losses determined from measu ments on a standard steel material, when applied to copp give values in agreement within 1·5% with published valu

Errors in the measurement of I, E, m, t and $\Delta\theta$ are ve small. Provided guard and specimen thermocouple matchi is maintained to better than ±10 μ V (1–2° C), the over accuracy is within ±3%. This estimate is based on t deviations of experimental points from computed curves a comparison of results with those of other observers.

CONCLUSIONS

The construction of an adiabatic calorimeter for t measurement of specific heat of small amounts of sol materials in the range 40–500° C has been described. method is given for the correction of errors due to ther losses based on measurements on a material of know specific heat. An overall accuracy of ±3% has been achieve

ACKNOWLEDGEMENTS

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The design of mercury thermometers for calorimetry

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The emergent column error and the uncertainties caused by irregular movement of the meniscus in an open-scale thermometer are discussed. It is considered preferable to calibrate calorimetric thermometers at total immersion unless the ambient temperature in use is considerably below that of the calorimeter. It is shown that irregularity of movement of the meniscus is, to a sufficiently close approximation, proportional to the external pressure coefficient of the thermometer β_e divided by the diameter of the bore d. If these are expressed in deg C × 0·001/cm of mercury and mm respectively, β_e/d should not exceed 15 when a reproducibility of reading of ± 0·002° C is desired. Further, it is undesirable to use a capillary having a diameter of less than 60 μm. The paper includes a chart by means of which the appropriate sizes of bulb and capillary tubing for a thermometer of given dimensions and scale length may be selected.

measurement of the temperature rise in accurate rimetry is usually effected either by a sensitive mercury mometer or by a platinum resistance thermometer. If ccuracy of the order of 0·001° C is necessary a resistance mometer must be used, but for slightly less accurate work possible to use a good mercury thermometer, with its antages of simplicity and cheapness. Since the thermoer is to be used for the measurement of a small difference emperature occurring in a short time, some of the weakses of the mercury thermometer are of no consequence, there remain two which may cause appreciable errors: ertainty in the temperature of the emergent column and gularity of movement of the mercury meniscus caused by iations in capillary forces. These errors can be minimized good design of the thermometer.

THE EMERGENT COLUMN ERROR

he emergent column correction to the temperature rise erved in a calorimetric experiment depends on the length legrees of the emergent column at the start and finish of experiment, and the difference between its temperatures use and at the time of calibration. The accuracy with ch these differences can be determined depends on the ign of both the calorimeter and the thermometer. The tion of the capillary of which the temperature is most ertain is that over which the temperature is changing n that of the calorimeter to that of the atmosphere. It herefore advantageous to reduce the number of degrees tained in this length by designing the calorimeter so as make it as short as possible, while avoiding any enlargent of the capillary of the thermometer in this region. It lear that calculation of the correction is simplified if the e is uniform throughout the length which is not immersed he water, and under these conditions an initial exposed umn of 2 or 3° C, which normally occupies a length of to 18 cm, need not be exceeded.

or the calculation of the error introduced by the exposed umn into the measurement of a temperature difference, cases must be considered, (i) when the thermometer has n calibrated at the fixed immersion at which it is to be d, so that the emergent column was sensibly at a constant perature throughout the calibration, and (ii) when the mometer has been calibrated at total immersion so that temperature of the column varied with that of the bulb. et t be the initial temperature of the bulb in °C, Δt its in temperature, t_s and Δt_s the corresponding figures for emergent column, $t_{s(cal)}$ the emergent column temperature ing calibration, n the initial length of the exposed column in degrees, and α the apparent coefficient of expansion of mercury in glass. If the thermometer has been calibrated at the fixed immersion at which it is used, the correction to a measured temperature interval is given by

$$\alpha\left\{\Delta t[t_{s(cal)} - (t_s + \Delta t_s)] - n\Delta t_s\right\} \qquad (1)$$

which, if the stem temperature does not change during the experiment ($\Delta t_s = 0$), reduces to

$$0{\cdot}000\,16\Delta t(t_{s(cal)} - t_s) \qquad (2)$$

since for the accuracy needed we can assume an average value of 0·000 16 for α. If the thermometer has been calibrated at total immersion, the corresponding expressions are

$$0{\cdot}000\,16[\Delta t(t - t_s) + (\Delta t + n)(\Delta t - \Delta t_s)] \qquad (3)$$

and

$$0{\cdot}000\,16\Delta t[(t - t_s) + (\Delta t + n)] \qquad (4)$$

With a well-designed calorimeter the temperature of the air above it is not likely to change appreciably during the course of the experiment, so that Δt_s would be nearly zero were it not for the presence of a short length of column inside the calorimeter jacket. If the capillary is kept fine in this region, the condition $\Delta t_s = 0$ will still be very nearly satisfied. Expressions (2) and (4) will therefore apply, and their magnitudes are shown graphically for a temperature rise (Δt) of 3° C in Fig. 1. The slope of each line is proportional to Δt, and the partial immersion lines for any

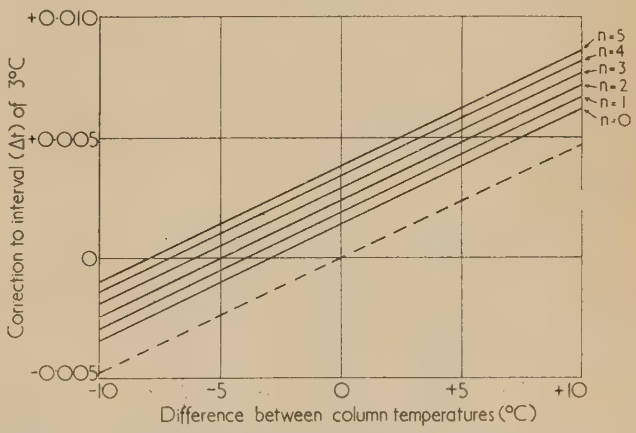

Fig. 1. Emergent column corrections to a temperature interval of 3° C

—— calibrated at total immersion (difference $t - t_s$).
– – – calibrated at working immersion (difference $t_{s(cal)} - t_s$).

value of Δt pass through the origin, while the intercepts of the $n = 0$ lines on the vertical axis are proportional to $(\Delta t)^2$.

It is clear that if the thermometer is calibrated at total immersion, it is particularly important to make n as small as possible, but the influence of n is by no means negligible when the calibration has been at partial immersion, since an appreciable proportion of n is inside the calorimeter jacket and must therefore change in temperature during the experiment. Since calibration at total immersion leads to more reliable results than calibration at a fixed immersion, it is obviously better to use the former technique when the calorimetric experiments are to be made near or a little below atmospheric temperature. Indeed, the only condition in which partial immersion calibration might be preferable is when the ambient temperature is normally considerably below that of the calorimeter. In these circumstances, calibration at partial immersion with the stem at approximately the working ambient temperature would probably lead to the least uncertainty in the results. In any case, if an overall accuracy of the order of ±0·002° C is required, all stem temperatures should be measured to within ±2° C.

CAPILLARY ERRORS

When a mercury thermometer is heated, the mercury meniscus first becomes more convex, thus increasing the capillary pressure which acts on the wall of the bulb. As the bulb is not rigid, its volume is increased by the excess internal pressure until the restoring force is sufficient to overcome it. The mercury meniscus then rises suddenly and becomes nearly flat again, and the process is repeated so that the meniscus moves in a series of jumps. In order to minimize these jumps, the capillary pressure should be reduced by using a large bore and the bulb stiffened by using a small diameter and thick wall. Since an open scale is obtained by the use of a fine capillary or a bulb of large volume (or some combination of the two) it is clear that jumping of the meniscus becomes more likely as the length of the degree is increased.

Ch.-Ed. Guillaume, in his *Traité Pratique de la Thermométrie de Précision* (Paris: Gauthier-Villars, 1889) deals with the question, and comes to the conclusion (p. 181) that the length of the degree can scarcely exceed 1 cm. Such a thermometer (divided to 0·1° C) requires a skilled observer and a good observing telescope if readings to an accuracy of about 0·002° C are to be obtained, and the modern practice is to use thermometers divided to 0·01° C and with a length of anything from 4 to 10 cm/°C. The apparent accuracy of such thermometers is frequently illusory, as the magnitude of the meniscus jumps is often about 0·005 to 0·010° C, and we have therefore carried out an investigation intended to establish the design factors which would lead to a satisfactory performance.

A reasonable supposition is that the tendency to jump would be proportional to the internal pressure coefficient of the thermometer β_i, that is, the reciprocal of the rigidity of the bulb, divided by the diameter of the capillary d. According to Guillaume (pp. 103 and 110) the external pressure coefficient β_e, expressed in thousandths of a degree Celsius/cm of mercury, is given by

$$\beta_e = 0{\cdot}52R_e^2/(R_e^2 - R^2) \qquad (5)$$

where R_e and R_i are the external and internal radii of the bulb in millimetres. The calculation can be made graphically by the use of Fig. 2. The internal coefficient is greater than the external coefficient by about 0·15 on account of the compressibility of mercury in glass. Fig. 2 shows that we are not likely to be concerned with values of β_e outside t limits 0·8 to 4·0, so that β_i will exceed β_e by from 4 to 19 Since an accuracy of ±10% is ample for our present nee it will suffice to use the external coefficient for comparat purposes, and this will simplify the presentation of the resul We have made some direct experimental determinations the coefficients, and the experimental values have been abo 25% less than those given by Guillaume's formula, but, we are only concerned with relative values, we shall use th calculated figures throughout. We have also based ou results on the effective diameter of the capillary (assume circular in section). Thermometer bores are normally som what elliptical, and the capillary forces are largely determine by the minor axis of the ellipse. The eccentricity of th capillaries we have used varies from 1·0 to 1·3 if two rath exceptional tubes are excluded, so that the ratio of the mino axis to the effective diameter varies by about ±8%. Con clusions based on effective diameter are thus sufficientl precise to be used for the control of the manufacture o thermometers from the normal supplies of tubing.

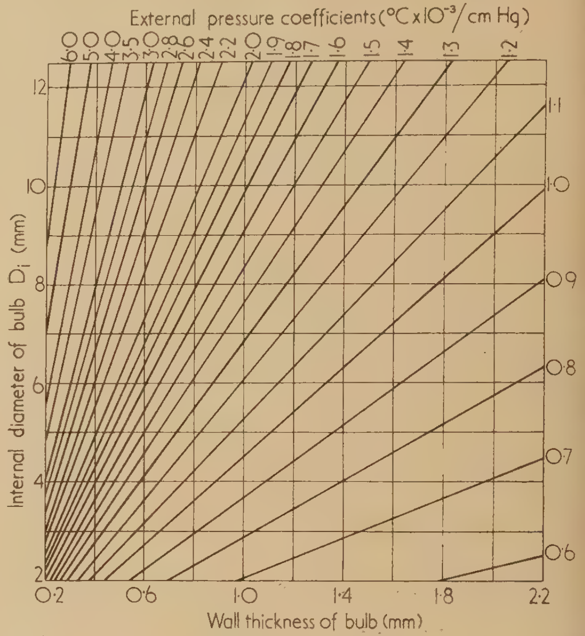

Fig. 2. External pressure coefficients in terms of bulb dimensions

It is well known that the primary standard thermometer of the Bureau International des Poids et Mesures, made b Tonnelot and by Baudin of Paris, are virtually free fro jumping, and the same thing applies to the dimensionall similar mercury-in-quartz thermometers which have bee studied by Moreau, Hall and Leaver.(1) All these thermo meters have approximately circular bores a little more tha 0·1 mm in diameter and calculated external pressure coef ficients of about 1·5, so that β_e/d is about 12. The fourtee experimental thermometers made for the present work wer therefore designed to have values ranging from 13 upward and they include two pairs in which similar values of $\beta_e/$ were obtained by the use of widely differing values of d.

EXPERIMENTAL PROCEDURE

The effect of variations in the capillary forces shows itsel in three ways: by the phenomenon of jumping, alread ntioned, by a change in reading when the thermometer is jected to vibration and by a difference between the dings obtained with rising and falling temperatures. All ee effects have been studied in the present work.

'or the first two, observations were made with a 35 mm ematograph camera so arranged that about 1° of the le occupied the diagonal of the frame. The camera was erated at 10 frames/s, and alternate frames were examined still projection of the negative. The observations were all de on a slowly rising temperature, since this is the condition which the behaviour of a mercury thermometer is most roducible. The bulb of the thermometer was protected m draughts and heated by radiation from a lamp focused it. The voltage on the lamp was regulated so as to give desired rate of rise of temperature, about 0·1° C/min. In eral, observations continued over a period of a minute, l the thermometer was subjected to vibration from the ntieth to the fortieth second. Vibration was effected by hort length of thick-walled pressure tubing attached to hammer of an electric-bell movement and operating on side of the thermometer near the top. An electric lamp he field of view indicated when the vibrator was working. The difference between the readings obtained with rising l falling temperatures was determined by comparing some he thermometers with a platinum resistance thermometer, one of the stirred-water baths normally used at the National ysical Laboratory for the testing of high-precision mercury rmometers.

THE EXPERIMENTAL THERMOMETERS AND THE RESULTS

The experimental thermometers were made by two different glish makers and were made with an openness of scale h as is commonly used in thermometers for bomb calori-try, the length of 1° C varying from 31 to 59 mm (B.S. -1954 permits scale lengths varying between 50 and mm/°C). According to the results of Carlton Sutton,(2) gas-filled thermometer should show greater regularity of ion than a vacuous thermometer. Carlton Sutton, how-r, used different thermometers to compare the behaviour he two types, and he gave no details as to bulb dimensions bore diameters. In order to check his results, therefore, ee of our thermometers were made originally in the cuous form and were afterwards gas-filled. Similar sets of servations were made in the two conditions so that a direct essment of the overall effect of gas-filling by the usual nufacturing procedures could be made.

The technical details of all our thermometers and the ults obtained from the cinematographic study of the vement of the meniscus are given in the table. The wall ckness of the blown bulbs of maker *E* is less uniform than t of the joined-on cylinder used by maker *B*, so that the culated pressure coefficients are rather less certain.

The two curves obtained with thermometer $B/2V$ when it s recording a slowly rising temperature are shown in Fig. 3 l may be taken as representative of the experimental ults. The two nearly straight lines are drawn through the h points of the curves of reading against time, and the ference between the two curves of each pair gives the rise used by tapping; in the present example 0·010 and 009° C. The maximum jump recorded in the absence of ration was 0·006° C, and with vibration 0·004° C. The ues recorded in the last three columns of the table are tted against β_e/d in Fig. 4. The rise caused by vibration learly proportional to β_e/d, and the linear relationship has

Dimensions and regularity of action of experimental calorimeter thermometers

Maker	No.	Constructional details	Bulb dimensions: Length (mm)	Bulb dimensions: Internal diameter (mm)	Bulb dimensions: Wall thickness (mm)	Bulb dimensions: Volume (cm³)	Capillary dimensions: Length of 1° C (mm)	Capillary dimensions: Effective diameter d (mm)	Capillary dimensions: Major axis / Minor axis	Calculated external pressure coefficient β_e $\left(\frac{°C \times 0·001}{cm\ Hg}\right)$	$\frac{\beta_e}{d}$	Rise of reading caused by vibration (°C)	Maximum meniscus jump: Without vibration (°C)	Maximum meniscus jump: With vibration (°C)
E	1	Gas-filled at low pressure: blown bulb	56	7·47	0·44	2·48	46	0·104	1·52	2·6	25	0·006	0·004	0·002
E	2	Gas-filled at low pressure: blown bulb	49	6·94	0·57	1·91	43	0·095	1·51	2·0	21	0·005	0·003	0·003
E	3	Gas-filled at low pressure: blown bulb	19	6·60	0·25	0·65	45	0·054	1·29	3·9	72	0·014	0·015	0·004
E	4	Gas-filled at low pressure: blown bulb	22	6·64	0·23	0·80	47	0·059	1·29	4·2	71	0·017	0·019	0·009
B	1*V*	Vacuous: joined-on bulb	13	7·16	0·90	0·52	58	0·043	1·05	1·45	32	0·005	0·008	0·007
B	1*G*	Gas-filled, 1 atm pressure: joined-on bulb	13	7·16	0·90	0·52	58	0·043	1·05	1·45	32	0·006	0·010	0·009
B	2*V*	Vacuous: joined-on bulb	34	8·68	0·40	2·02	59	0·083	1·02	3·3	40	0·010	0·006	0·004
B	2*G*	Gas-filled, 1 atm pressure: joined-on bulb	34	8·68	0·40	2·02	59	0·083	1·02	3·3	40	0·004	0·005	0·006
B	3*V*	Vacuous: joined-on bulb	10	8·46	0·45	0·55	46	0·050	1·00	3·0	60	0·013	0·030	0·030
B	3*AV*	Vacuous: joined-on bulb	20	5·25	1·41	0·43	31	0·050	1·00	0·9	18	0·005	0·008	0·006
B	4*V*	Vacuous: joined-on bulb	10	8·10	0·45	0·52	48	0·047	1·05	2·8	61	0·013	0·025	0·027
B	4*G*	Gas-filled, 1 atm pressure: joined-on bulb	10	8·10	0·45	0·52	48	0·047	1·05	2·8	61	0·011	0·010	0·030
B	5*V*	Vacuous: joined-on bulb	52	7·24	0·90	2·14	58	0·086	1·13	1·45	17	0·003	0·000	0·000
B	6*V*	Vacuous: joined-on bulb	67	6·44	1·15	2·19	58	0·088	1·13	1·15	13	0·003	0·000	0·002

been transferred to each of the graphs of maximum jump as a broken line. The observed points fit the line reasonably well, though with considerably more scatter. This is understandable, since the rise caused by vibration rests on the mean of observations over an appreciable length of the scale, while the maximum jump may be determined by a local imperfection in the capillary. The uncertainties are, as might be expected, greater for the higher values of β_e/d, but for values of β_e/d up to 40, the maximum jump is practically the same as the rise caused by vibration.

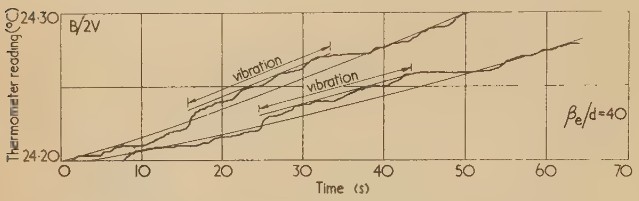

Fig. 3. Effect of vibration and magnitude of jumps with thermometer having $\beta_e/d = 40$

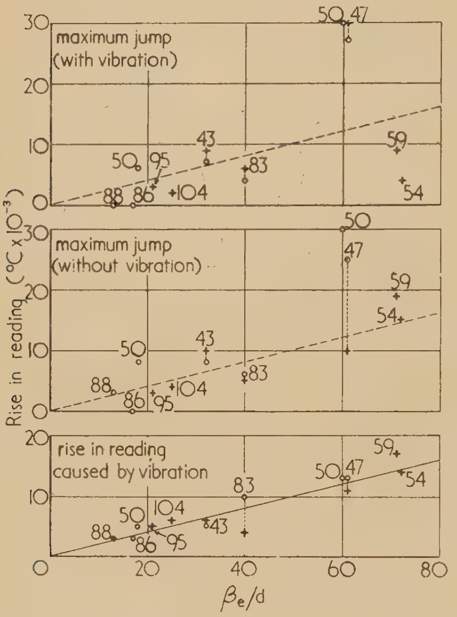

Fig. 4. Relation between β_e/d and regularity of action

Numbers beside observed points indicate effective bore diameters in μm.

⊙ vacuous thermometer + gas-filled thermometer.

The improvement made by using a bulb with a much thicker wall is shown directly by a comparison of the results given in the table for thermometers *B*/3*V* and *B*/3*AV* (bore = 50 μm). The second of these used the same capillary as the first, but the bulb was changed so as to bring β_e/d down from 60 to 18. This thermometer gave a particularly bad jump at a reading of 24·675° C, and Fig. 5 shows that this was reduced from 0·025 to 0·006° C by the change of bulb.

The effect of increasing the thickness of the bulb wall on the lag of the thermometer is shown in Fig. 6. The lags were measured in a bath of rapidly stirred water, the method being to plunge the thermometer into the bath and to record the passage of selected graduations on a tape recorder. The time intervals were determined by playing-back the t against a stop-watch as often as was necessary to time all observations. In this way, lag constants of a few seco could be observed with a reproducibility of about ±0· The thermometers were divided into three groups, hav mean internal bulb diameters of 4·7, 5·5 and 7·9 mm a small corrections were applied to the observed lags to ta account of any variations in the diameter of an individ bulb from the mean of its group.

As regards the effect of gas-filling, we have not confirm Carlton Sutton's results, except, perhaps, for high values β_e/d. Fig. 4 shows that the effect of vibration on thermome *B*/1 (43 μm bore, $\beta_e/d = 32$) was virtually unchanged by g filling, but thermometers *B*/2 (83 μm bore, $\beta_e/d = 40$) a *B*/4 (47 μm bore, $\beta_e/d = 61$) were possibly somewhat i proved.

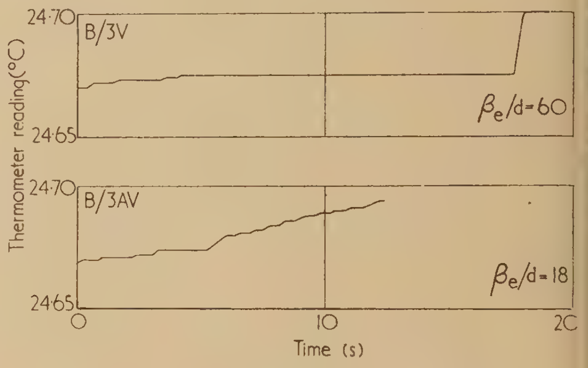

Fig. 5. Effect of changing β_e (d constant)

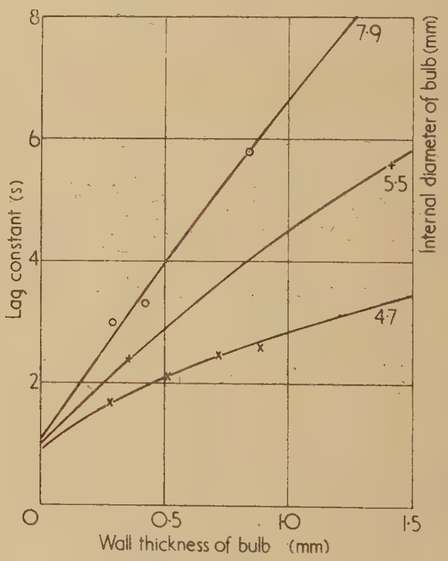

Fig. 6. Effect of bulb dimensions on lag of thermomete

Some additional tests were carried out by compar thermometers *B*/3*AV* (50 μm bore, $\beta_e/d = 18$), *B*/5*V* (86 bore, $\beta_e/d = 17$) and *B*/6*V* (88 μm bore, $\beta_e/d = 13$) wit platinum resistance thermometer in a water bath with a slow rising temperature. The circulation of water caused a cert amount of vibration, but manual tapping produced readin 0·002° C higher with thermometers *B*/5*V* and *B*/6*V* a 0·006° C higher with thermometer *B*/3*AV*. These figu e well with 0·003 and 0·005° C obtained with mechanical ration applied to an otherwise motionless thermometer. vas evident during the water-bath test that the action of mometer *B*/3*AV* (50 μm bore) was inferior to that of the er two, and the difference is perceptible on the curve of effect of vibration (Fig. 4) while it is obvious in the size he maximum jumps.

he water-bath readings were extended to include a ermination of the differences between the readings obtained n rising and falling temperatures. With thermometers *V* and *B*/6*V*, falling readings were higher by 0·004° C en the thermometers were not tapped, and this difference reduced to 0·002° C by tapping. The corresponding res for thermometer *B*/3*AV* were 0·017 and 0·009° C.

CONCLUSIONS

t seems clear from the above results that if a reproducibility eading of one or two thousandths of a degree is required, necessary that the value of β_e/d should not exceed about Further, since a thermometer of 50 μm bore (*B*/3*AV*) e an appreciably inferior performance to thermometers of er bore having similar values of β_e/d, the minimum bore neter should be made somewhat higher than this: a figure 0 μm would seem to be reasonable.

f we accept the condition $\beta_e/d = 15$, and combine this n the expression for β_e in terms of bulb dimensions, taking o account the expansion coefficient of mercury in glass, we e

$$D_i\left(1 - \frac{D_i^2}{D_e^2}\right) > 2\cdot7\sqrt{(L_d/L_b)} \qquad (6)$$

ere D_i and D_e are the internal and external diameters of bulb and L_b and L_d are the lengths of the bulb and of one ree Celsius of the scale respectively.

ig. 7 gives a means of applying this criterion to any ticular case. If, for example, it is desired to use a capillary 0·1 mm effective diameter, the possible combinations of b diameter and wall thickness are given by points along radial line marked 0·10. As the bulb diameter is reduced, nner walls become possible, but at the same time the bulb gth (in terms of the length of a degree of the scale) must increased. The necessary bulb lengths are given by the ersections of the radial line with the curved lines. For mple, with the 0·10 mm bore and a bulb of internal meter 7 mm, the bulb wall would have to be 0·85 mm k and the length of the bulb would be 1·2 times that of degree. Clearly, the utilization of material is greatest en there is least restriction on the maximum permissible gth of bulb, so that in drawing up a specification for a rmometer it is desirable to allow the maker as much tude as possible in this dimension.

ig. 7 has been extended to show (in broken lines) the use capillaries finer than 60 μm bore. This has been done to w the general shape of the curves more clearly, and it also ws that the range of usable material would be very little reased were these finer bores to be used.

f our proposed criterion for bulb and capillary dimensions ccepted, there is nothing to choose between the regularity action of vacuous and gas-filled thermometers. If gas-filling is employed the internal pressure should not exceed ½ atm if variations in the internal pressure caused by small changes in temperature of the upper part of the thermometer are to be negligible.

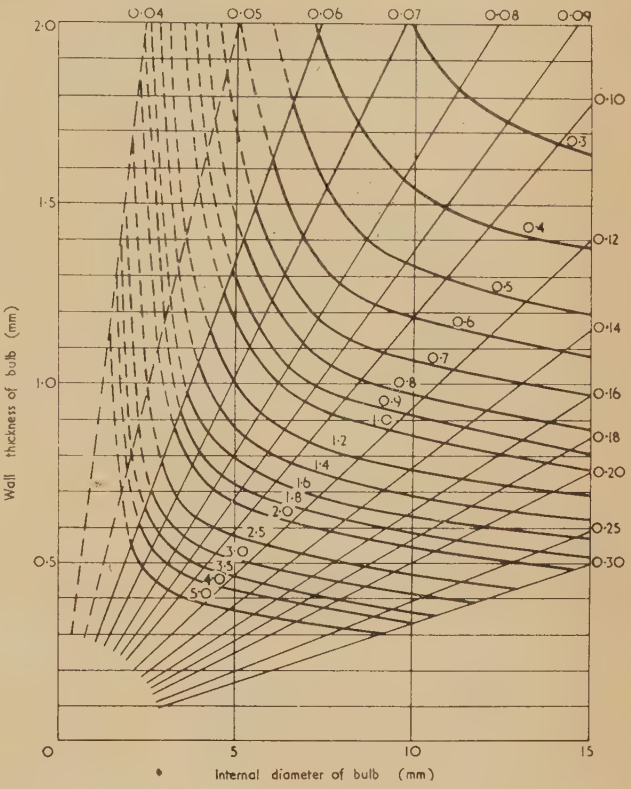

Fig. 7. Bulb dimensions required to make $\beta_e/d = 15$ for a range of capillary sizes

Radial lines give bore of capillary in mm.
Curved lines give length of bulb as a fraction or multiple of length of 1° C of scale.

Measurements made with thermometers employing a wide range of sizes of capillary show that the lag constant is not likely to exceed 8 s with any reasonable choice of materials.

ACKNOWLEDGEMENTS

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Method of double-beam spectrophotometry in the vacuum ultra-viol

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An apparatus is described which permits the measurement of absorption coefficients in the far vacuum ultra-violet, using an unsteady radiation source. The beam emerging from a monochromator is divided, and one part is passed through an absorber cell. Two photomultipliers and a bridge network are used to measure the intensity ratio with and without an absorber in the cell. Absorption coefficients can be measured with an accuracy of 1% or better at wavelengths down to 800 Å.

The photographic plate has been widely used to record spectra in the vacuum ultra-violet, but its use for quantitative measurements of absorption depends upon the employment of a radiation source whose intensity can be maintained constant over the time of an experiment. At wavelengths below 1000 Å this condition becomes difficult to fulfil and the difficulty is aggravated by the long exposures needed to record the weak lines which most sources emit at shorter wavelengths.

Condensed-spark sources have been developed$^{(1, 2)}$ which will yield measurable amounts of radiation from 200 Å upwards, but it has been found impossible to maintain line intensities constant to more than a few per cent in successive exposures. There is a variation, not only of intensity, but also of the intensity distribution among the lines of a spectrum, so that it is not even possible to measure the relative absorption coefficients for two lines on the same exposure. No greater accuracy is to be expected by the use of a monochromator and photomultiplier system. The radiation output from the condensed spark used by the author consisted of a series of pulses a few tens of microseconds long, and repeated at 20 ms intervals. The heights of these pulses fluctuated randomly about a mean value and it was only by integrating the photomultiplier output over several seconds that these fluctuations could be reduced to a few per cent. There was also a slow variation of the average intensity, which changed by a few per cent in the space of a minute, so that the absorption coefficients could be measured to no greater accuracy than with a photographic plate.

In the far vacuum ultra-violet it is not practicable to divide a beam of radiation by means of a partially reflecting surface as is commonly done in spectrophotometry of the infra-red and visible regions. This paper describes an alternative beam-splitting device and shows that it may be used to give a considerable increase in the accuracy of the measurement of absorption coefficients.

APPARATUS

The intensity of a beam of radiation in the vacuum ultra-violet can be measured by allowing the beam to fall upon a fluorescent screen, and measuring the resultant visible intensity with a photomultiplier. In the present system (see Fig. 1) a thin strip of metal M coated with sodium salicylate is allowed to intercept part of the divergent beam coming from the exit slit E of a monochromator. The visible radiation from this screen is focused by a condensing lens L on to a photomultiplier PM_1 placed to one side of the beam. The rest of the beam from the monochromator is passed through the absorbing cell C and falls upon a larger fluorescent screen. The light from this screen is detected by a second photomultiplier PM_2. The two photomultiplier outputs vary in the same way, and however the source intensity varies the anode currents at any instant are in a constant ratio. T ratio depends only on the geometry of the system and on amount of absorption that takes place, and absorption coe cients can be measured by comparison of the ratio with a without an absorber present.

It was desired to measure the absorption of radiation b gas, and so the beam from the monochromator exit slit w passed from the vacuum system into the absorption c through a thin collodion window$^{(3)}$ W. This window w about 50 Å thick, and was mounted on a removable dev that permitted easy replacement.

The beam-splitting device was placed in the absorption c close behind the window. The absorption cell was 60 long, the length being determined by the divergence of radiation beam and the maximum available diameter of photomultiplier cathode. There were the usual arrangemen for admitting and evacuating gases, and for measuring the g pressure during an experiment. The fluorescent screens we made by triturating sodium salicylate under ether and allo ing the resultant fine suspension to settle slowly on to a gla or metal surface. Adhesion was ensured by dissolving small quantity of apiezon grease in the ether.

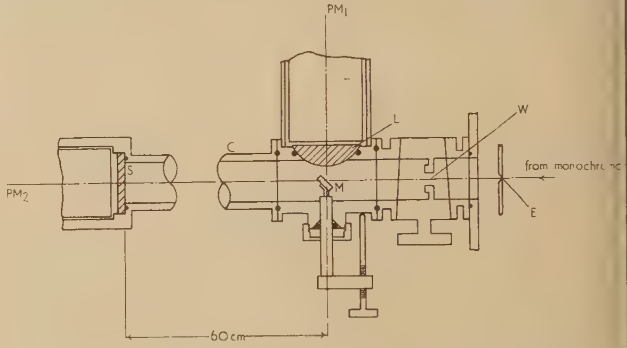

Fig. 1. Beam-splitting device and absorption cell

MEASUREMENT OF INTENSITY RATIO

Since the radiation was received in short pulses it was co venient to use cathode-follower voltmeters to measure t peak intensities. These voltmeters were arranged to avera the peak intensity over 0·5 s. The outputs of the voltmete were then compared in a bridge network in which arrang ments were made to balance out spurious readings due to da current and scattered radiation. The voltmeters may regarded as devices for producing a voltage drop at the outp terminals proportional to the light input to the photomul pliers. The circuit of one of these voltmeters is shown Fig. 2, and the circuit of the ratio-measuring bridge in Fig. The voltage pulses coming from the photomultipliers we ative-going so that it was necessary to allow the cathodes he voltmeters to rise to a conveniently high voltage when circuit was at rest. The circuit was accordingly designed llow the cathodes to lie as + 70 V, pulses larger than this being anticipated.

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* Now at The Queen's University, Belfast.

he photomultiplier receiving light from the beam-splitting en was called the "monitor" and was a type 9502 (by I.I. Electronics Ltd.). The other was called the "detector"

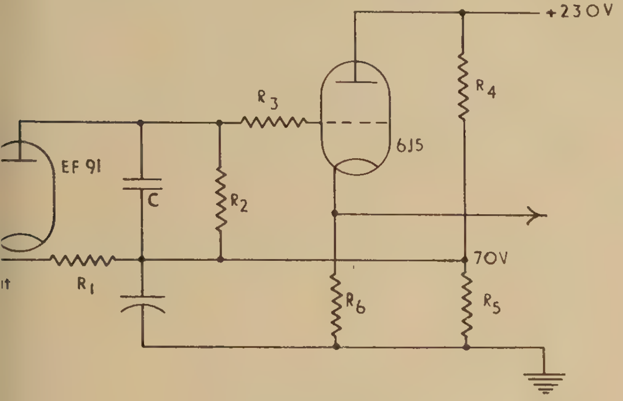

Fig. 2. Valve-voltmeter

$R_1, R_3 = 1\ \text{M}\Omega$
$R_2 = 50\ \text{M}\Omega$
$R_4 = 33\ \text{k}\Omega$
$R_5 = 13\ \text{k}\Omega$
$R_6 = 6\ \text{k}\Omega$
$C = 0{\cdot}01\ \mu\text{F}$

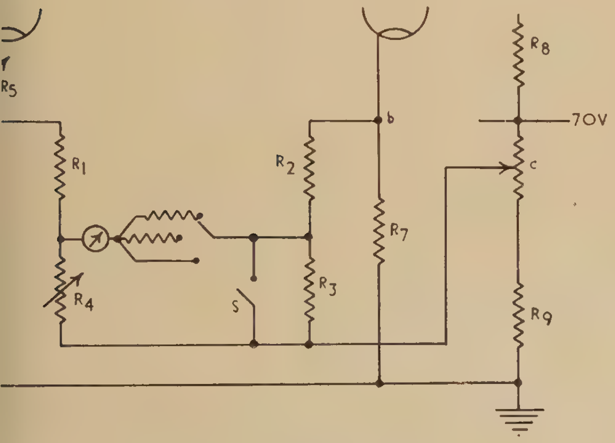

Fig. 3. Bridge network

$R_1, R_2 = 1\ \text{M}\Omega$
$R_3, R_4 = 10\ \text{k}\Omega$
$R_5 = 2\ \text{k}\Omega$
$R_6, R_7 = 6\ \text{k}\Omega$
$R_8 = 33\ \text{k}\Omega$
$R_9 = 11\ \text{k}\Omega$

l for this a type 9514 (by E.M.I. Electronics Ltd.) was used ause its larger photocathode would intercept the wide m of radiation at the far end of the absorption cell. ere was a dark current from the monitor of 0·1 μA, and of μA from the detector. These dark currents, if passed ough the bridge would result in a false balance ratio, and vas necessary to provide potentiometers to balance out the tages which they produced across the voltmeters. The dge was adjusted so that points *a*, *b* and *c* (Fig. 3) were all at same potential when the dark currents were flowing. The tch *S* was included to allow this to be done.

With the photocurrents flowing the bridge could be balanced adjusting the resistance box R_4, so that no current flowed ough the galvanometer. It is easily shown that the resisce R_4 required to achieve this is proportional to the ratio the photocurrents. The experimental technique used uires only a knowledge of some quantity proportional to this ratio and provided that all the other resistances in the bridge circuit are kept constant, a measurement of R_4 is the only required information.

EXPERIMENTAL TECHNIQUE

In the particular case of absorption by a gas the amount of radiation reaching the detector will vary according to Beer's Law. If the pressure of the gas is p, and the length of the absorption path is l, the intensity at the detector will be I_p, where:

$$I_p = I_o e^{-\alpha p l}$$

α being the absorption coefficient, I_o the intensity of radiation at the monitor screen, and l the distance between the beam-splitter and the detector screen. The two photocurrents will be proportional to I_p and I_o and we have:

$$R_4 = k(I_p/I_o) = k.e^{-\alpha p l}$$

where k is a constant depending on the geometry, the fluorescence efficiency, the photomultiplier sensitivities and the circuit constants.

Thus

$$\log_e R_4 = -\alpha p l + \log_e k$$

and a graph of $\log_e R_4$ against p will have a slope proportional to α, the absorption coefficient.

Gas was admitted to the absorption cell to a pressure sufficient to cause 90% absorption. The resistance box R_4 was adjusted to balance the bridge, and the value of R_4 and the corresponding pressure were noted. The gas pressure was then reduced in small steps. and a set of readings was made of the balancing R_4's and the appropriate pressures. The slope of the graph plotted, together with a knowledge of the path length gave the absorption coefficient.

RESULTS

Fig. 4 shows a typical example of the graphs plotted during a series of experiments on the absorption of oxygen in the

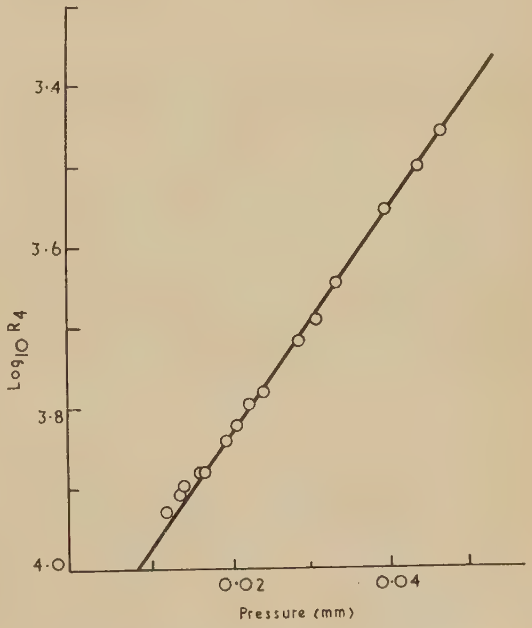

Fig. 4. Absorption by oxygen at 1555.3 Å

(Log$_{10}$ R_4 plotted for convenience.)

Schumman-Runge continuum. The circles indicate the error in each measurement of R_4 and p. The absorption cross-section computed from this graph is $16{\cdot}1 \pm 0{\cdot}15$ megabarns ($1\ \text{MB} = 10^{-18}\text{cm}^2$). The improvement in accuracy over a single-beam method of spectrophotometry may be seen by comparing the results obtained in the measurement of the absorption of atomic oxygen in the far vacuum ultra-violet:

Wavelength (*Å*)	*Absorption* (*double beam*)	*Absorption* (*single beam*)(4)
1085	$0\ (< 0{\cdot}15)$	0
991	$5{\cdot}11 \pm 0{\cdot}05$	$4{\cdot}75 \pm 1{\cdot}5$
988	$7{\cdot}25 \pm 0{\cdot}05$	$9{\cdot}2 \pm 1{\cdot}2$ at 985 Å
923	$16{\cdot}00 \pm 0{\cdot}10$	$14{\cdot}3 \pm 1{\cdot}9$ at 920 Å
835	$14{\cdot}20 \pm 0{\cdot}05$	$15{\cdot}2 \pm 0{\cdot}8$ at 833 Å

The accuracy to which measurements can be made depends upon the intensity of the radiation from the source. As the intensity falls it is found that a balance can be obtained over an increasing range of values of R_4. An increase of meter sensitivity merely introduces the noise of the circuit components, and it is found that the radiation intensity is the limiting factor. For the same reason amplification of the photomultiplier outputs before the voltmeters is both unnecessary and undesirable.

CONCLUSIONS

The system is capable of yielding results with an accura of 1% or better, provided a sufficiently powerful source radiation is available. The optical design of the syst makes it impossible to scan a region of the spectrum at a fix absorber pressure, since the beam-splitting device does n "see" the same part of the diffraction grating as the detecti screen, and so an emerging beam of monochromatic radiati falls first of all on to one screen, then, as the waveleng setting is adjusted, on to both screens, and finally on to t other screen. The scanning method might be feasible the piece of metal pushed into the path of the beam is replac by a grid of wires coated with the fluorescent material. T grid would then sample the whole area of the beam uniform

ACKNOWLEDGEMENT

The author would like to thank Professor R. W. Ditchbu for his valuable advice and encouragement during the cou of this work.

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Method of reducing the effects of vibration in a magnetic ring balance

By C. A. Clark, Ph.D., A.Inst.P. and J. E. Whittle, The Mond Nickel Co. Ltd., Birmingham, 16

[*Paper received* 3 *October*, 1958]

A damping arm, pivoted near its centre of gravity, has been added to the ring of a Sucksmith magnetic balance in order to reduce the response to external vibration. The mass of the damping arm is distributed to provide a large inertia to vibration at the resonance frequency of the spring system, without appreciably affecting its sensitivity.

In a light mechanical system controlled by springs, one of the most difficult problems is often that of eliminating effects due to external vibrations, which may be transmitted through the supporting frame.

An example of this type of system is the Sucksmith ring balance* in which the force acting on a specimen S, placed in an inhomogeneous magnetic field, is transmitted by a quartz tube to a circular spring supported at its highest point T, as shown in Fig. 1. The distortion of the ring is magnified by the optical-lever method, using four plane mirrors $M_1, \ldots M_4$, in the apparatus described here. After reflexion at the mirrors, the beam of light is focused in the focal plane of a microscope fitted with vertical traverse. The two flat spirals, S_1 and S_2, provide lateral constraint and supplement the restoring force supplied by the ring spring when the specimen is displaced.

The magnetic force f_σ, acting on a specimen of mass m and specific intensity of magnetization σ, in a field gradie dHy/dx, is balanced by the elastic forces in the spring, so th the corresponding specimen displacement x_σ is given by th equation

$$kx_\sigma = f_\sigma = \sigma m\,(dHy/dx) \qquad ($$

where k is the spring constant. It is necessary that the volun and displacement of the specimen should be small, so that can be assumed that the field gradient is effectively consta Thus, in the apparatus described here, an iron sample mass 80 mg experiences a displacement of approximate 0·005 cm, but this is magnified by the optical lever to give deflexion of 2·2 cm at the microscope.

Because of its small mass, this mechanical system is readi set into vertical oscillation by vibrations transmitted throug the supporting frame. This effect may be reduced by electr magnetic damping, oil damping, etc., but these methods a not usually completely successful. An alternative method damping, described below, virtually eliminates all vibration e moving system. The apparatus has been modified so under static conditions the force on the controlling gs is small, but under oscillating conditions the inertia uch increased, the natural frequency of vibration being about two cycles per second. The springs do not ond, therefore, to the vibrations of much higher frequency nally encountered.

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* Sucksmith, W. *Proc. Roy. Soc. A*, **170**, p. 551 (1939).

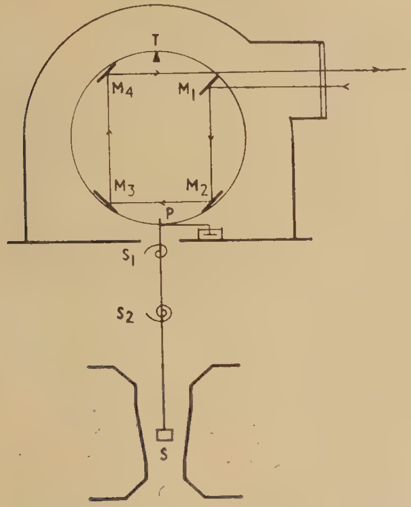

Fig. 1. Schematic diagram of Sucksmith ring balance

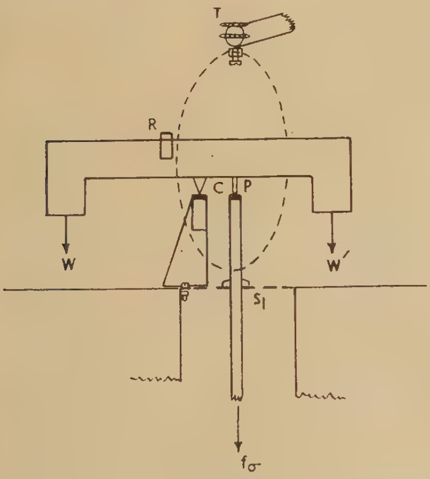

Fig. 2. Diagram of damping arm on ring balance

is effect is achieved, as shown in Fig. 2, by employing nced weights WW', with a connecting arm supported at mid-point on an agate knife edge C resting on an agate te. A stainless steel point attached to the connecting arm P is in contact with an agate plate cemented to the top of quartz support tube of the ring balance. Contact at P btained by adjusting the rider R until a small deflexion is erved in the microscope, corresponding to a displacement of the sample. The equivalent out of balance force f_1 at P st then be equal and opposite to the corresponding force , exerted by the spring. The displacement at P corre- nds to an applied force of only about 0·3 gwt, but the al effective mass of the moving system $2W$ is about 100 g. t is readily shown that the effect of the damping arm is to dify the spring constant by an amount $2Wg/l^2$ where g is the distance of the centre of gravity of the damping arm below the pivotal point, C, and l is the distance CP. When, by applying a magnetic field, the sample is displaced through an additional distance x_σ, the damping arm rotates through an angle θ, and the weight $2W$, acting through the centre of gravity, exerts a moment about C. Taking moments about C, we have

$$2Wg \sin\theta + k\,(x_\sigma + x_1)\, l \cos\theta = (f_\sigma + f_1)\, l \cos\theta \quad (2)$$

In practice x_σ does not exceed 0·005 cm and l is about 2 cm, so that it is permissible to substitute $\sin\theta = x_\sigma/l$ and $\cos\theta = 1$. Since $kx_1 = f_1$, it follows that

$$f_\sigma = [k + (2Wg/l^2)]\, x_\sigma \quad (3)$$

It is possible to make g quite small, about 0·1 cm, without making the damping arm unstable during operation of the ring balance. The quantity $2Wg/l^2$ is then about 2·5, compared with a value of about 2000 for k. It is clear, therefore, that small variations in the quantity $2Wg/l^2$, due to changes in ambient temperature, cannot significantly affect accuracy and reproducibility.

A photograph of the apparatus, showing the damping arm in relation to the normal ring system, is shown in Fig. 3.

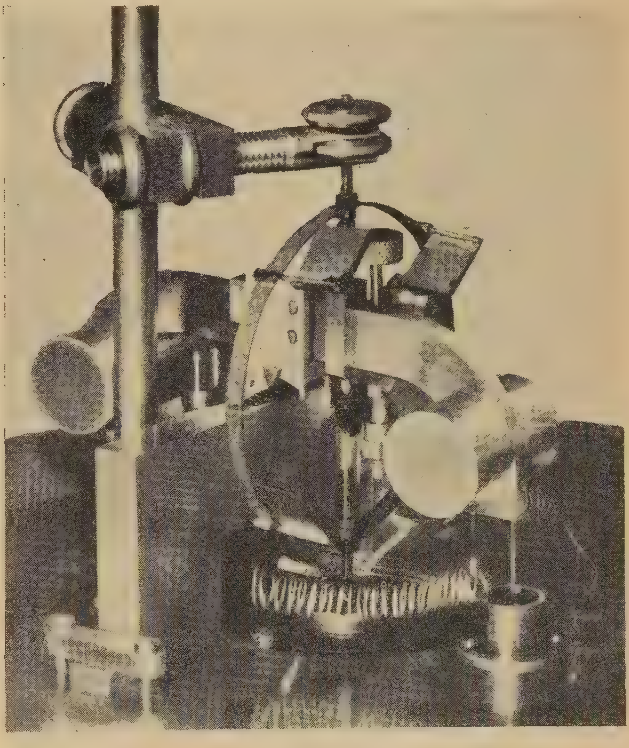

Fig. 3. Photograph of the ring spring with the damping arm in position

Oil-damping in a dash pot is applied at one end of the damping arm, to prevent the slight overshoot which otherwise occurred when the magnetic field was switched on or off.

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Contour mapping microdensitometer

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[*Paper received* 30 *October*, 1958]

The instrument described in the present paper is basically a scanning microdensitometer in which a gating circuit is utilized in conjunction with an optical printing system to plot automatically a contoured density map of the photograph which is being scanned. The gating circuit used is comparatively simple and extremely stable and permits the insertion of as many contours as are required, at specified values of density.

It has been the practice so far, whenever it has been necessary to prepare a contoured density map of a photograph, to plot the contours manually. The procedure generally adopted for this purpose has been to locate the co-ordinates of successive points having the same density from a series of microphotometer records taken with a small separation between successive traverses.(1) This is necessarily a very laborious process, particularly when the number of density contours to be plotted is more than one or two.

The present paper describes how this task has been simplified by modifying a microphotometer to plot such density contour maps directly. The circuit used is comparatively simple and extremely stable and permits the insertion of as many contours as are required, at specified values of density.

DESCRIPTION OF THE APPARATUS

The operation of the instrument can be easily followed from Fig. 1, which is a schematic diagram of the apparatus. The plate *P* which is to be mapped is mounted along with an unexposed plate *P′* on the carriage of the microphotometer and scanned along a series of parallel lines separated by a constant small interval. A small portion of *P* is illuminated by the lamp *L* through the condensing lens *C*, and a magnified image of this area is formed by the microscope objective *O* on the scanning aperture *S*. The signal from the photomultiplier *PM* which is proportional to the density of the plate at this point is led to a gating circuit *G* which triggers the discharge tube *A* whenever the density of the plate *P* passes through any one of a number of pre-set values corresponding to the desired contours. This results in a small spot (the reduced image of the aperture *S′* formed by the microscope objective *O′*) being printed on the plate *P′* at these points. These spots join up to give practically continuous contour lines if the lateral spacing between successive scans is properly chosen.

MECHANICAL DETAILS

The microphotometer used was a Hilger non-recording microphotometer, which was modified as described below.

The scanning mechanism. The screw of the microphotometer was driven by a synchronous motor through a reduction gear box and a friction clutch at a rate of 20 rev/min, so that the plate was scanned at a speed of approximately 0·5 mm/s. Higher or lower scanning speeds could be obtained by varying the gear ratio used. With the friction clutch disengaged, the screw could also be rotated manually, so that the carriage could be returned in a few seconds to its starting point for the next scan. Two microswitches were fitted to the carriage which could be set to limit the length of the plate scanned to the desired region. A transverse micrometer movement provided with a click stop was also fitted to the carriage, so that it could be moved laterally through a fixed distan between successive scans.

The contour recorder. The microprojector which pri the contours was attached to a rigid cast iron bracket whi was mounted on the base casting of the instrument, to t left of the scanning microscope. The optical system of t microprojector gave an overall reduction ratio of 15, so th spots 0·1 mm in diameter were obtained on the plate with a 1·5 mm pinhole at *S′*. The light source used was argon lamp of the type used in commercial photograph contact printers, which gives off an intense bluish-purple glo

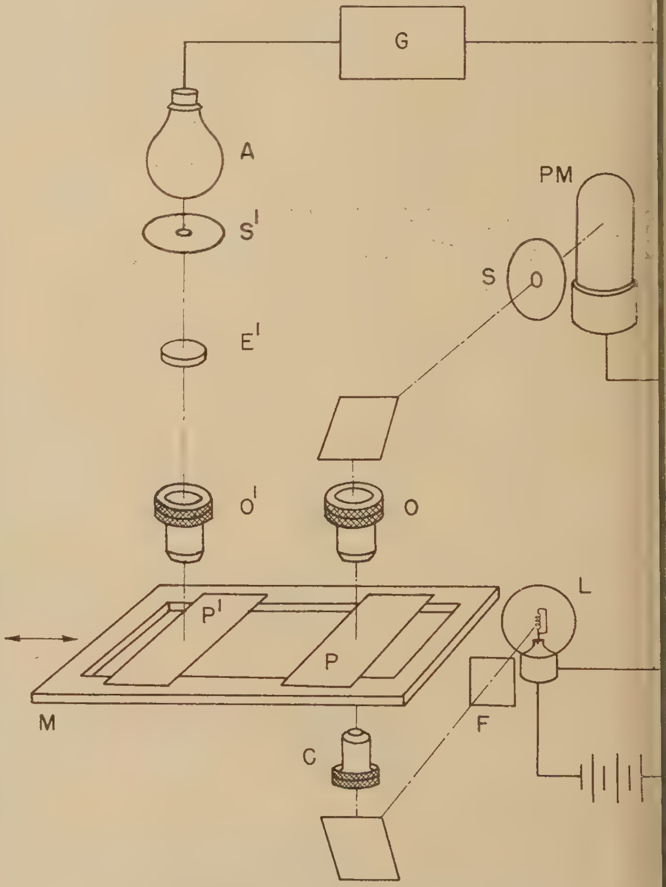

Fig. 1. Schematic diagram of the apparatus

M, microphotometer carriage; *P*, plate to be mapped; *P′*, unexposed plate; *C*, condenser; *O*, *O′*, microscope objectives; *E′*, projection eyepiece; *S*, *S′*, apertures; *PM*, photomultiplier tube; *G*, gating circuit; *A*, argon glow lamp; *L*, projection lamp; *F*, minus-blue filter; *R*, rheostat.

Since the spot printing attachment could not convenient be enclosed in a light-tight box, the apparatus was operate in a dark room. The risk of fog due to scattered light fro the scanning beam was minimized by placing a minus-blu nce OY2) filter *F* in front of the lamp *L*, and using -sensitive (Ilford Ordinary) plates for recording the ours.

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CIRCUIT DETAILS

ne electronic circuit consists of two distinct sections— ogarithmic circuit and the gating circuit.

e logarithmic circuit. The logarithmic photoelectric uit used in this instrument is similar to that utilized in a r densitometer designed by the authors(2) and employs otomultiplier tube operated at constant anode current e light sensitive element.(3) Under these conditions, the ion between the light flux F and the dynode voltage V the form:

$$F \propto (V/V_1)^{-N\beta} \qquad (1)$$

re V_1 and β are tube constants, and N is the number of ode stages. If the dynode voltage is then applied to an lifier with a logarithmic response, the output voltage v ven by the relation

$$v = -(1/N\beta)\log F + K \qquad (2)$$

re K is a constant, and is therefore proportional to the rithm of the incident light flux. Since $N\beta$ is of the r of 6·6 for nine-stage photomultiplier tubes such as RCA 931-A,(4) a logarithmic response can be easily ined over a fairly wide range with such a circuit, even an amplifier having a logarithmic characteristic over a paratively restricted range.

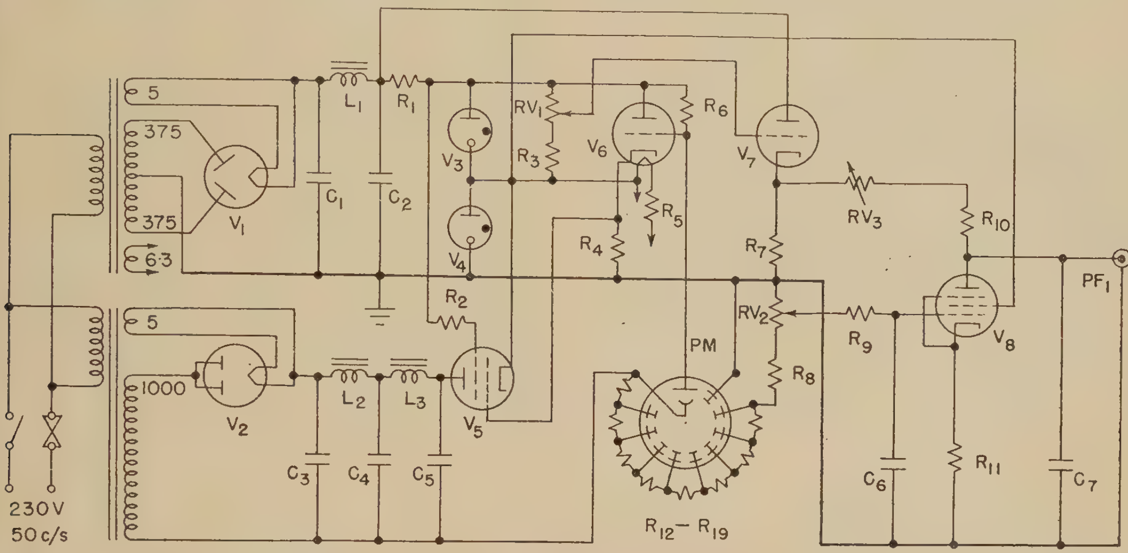


Fig. 2. Diagram of the logarithmic photoelectric circuit. Resistors are ±10%, 1 W carbon, except where otherwise specified

R_1 = 5 kΩ, 10 W
R_2 = 1 kΩ
R_3 = 15 kΩ, w.w.
R_4 = 330 kΩ
R_5 = 5 Ω, w.w.
R_6 = 150 MΩ
R_7 = 33 kΩ, 2 W
R_8 = 10 kΩ, w.w.
R_9 = 100 kΩ
R_{10} = 50 kΩ, w.w.
R_{11} = 10 kΩ, w.w.
R_{12}–R_{19} = 15 kΩ, w.w.
RV_1 = 10 kΩ
RV_2 = 5 kΩ
RV_3 = 50 kΩ
C_1 = 16 µF
C_2 = 32 µF
C_3–C_5 = 4 µF, oil filled
C_6, C_7 = 0·05 µF
V_1 = 5Y3 GT
V_2 = 5R4 GY
V_3 = VR 75
V_4 = VR 105
V_5 = 807
V_6 = 6SF5
V_7 = 6J5
V_8 = 6SK7
PM = 931 A
L_1 = 8 H
L_2, L_3 = 20 H

ig. 2 is a diagram of the actual circuit. The high voltage ly for the photomultiplier tube utilizes a half-wave fier V_2 and a two-section capacitor-input filter. The vidual dynodes are fed from a chain of equal bleeder tors, the current through which is controlled by a ative feedback circuit consisting of a cathode follower nd a series regulator tube V_5.

n adjustable fraction of the voltage developed across the resistor in the dynode bleeder chain is tapped off by the potentiometer RV_2 and applied to the grid of the logarithmic amplifier, which is a variable-μ pentode V_8. Since the transfer characteristics of the type 6SK7 tube used are closely logarithmic for grid potentials between −12·5 V and −30 V, RV_2 is set so that this range of imput voltages is obtained when the dynode voltage varies from 50 to 120 V per stage, which is the best operating region for the photomultiplier. This corresponds to an illumination range of about 300 : 1, that is to say, to a density range of approximately 2·5.

A separate power supply stabilized by two voltage regulator tubes V_3, V_4 is used to provide the screen and cathode voltages for V_5 as well as the plate voltage for V_6 and the screen voltage for V_8. The plate voltage for V_8 is taken from a cathode follower V_7 which constitutes a low impedance, stabilized supply, whose voltage can be set by means of the potentiometer RV_1.

The gating circuit. Most of the systems described so far for obtaining discrete contours from a continuously varying input have involved the use of relatively elaborate circuits.(5, 6) This drawback is overcome in the arrangement used in the

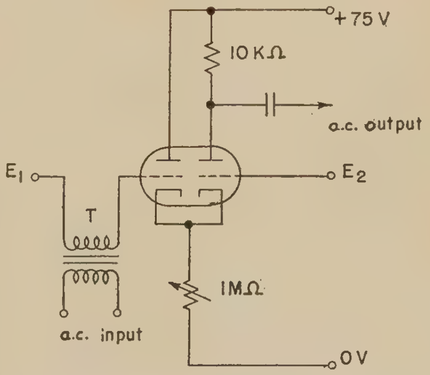


Fig. 3. Diagram of the basic gating circuit
E_1, input voltage; E_2, reference voltage.

present set up, which utilizes only one tube for each density contour.

Fig. 3 is a diagram of the basic gating circuit. The d.c. output voltage E_1 from the logarithmic amplifier is applied to one grid of a double triode, while a reference voltage E_2 corresponding to the desired density contour is used to bias the other grid. Since the common cathode resistor has a fairly high value, the cathode follows the grid which is at the higher potential, with the result that the first half of the tube cuts off whenever E_1 is less than E_2, while the second half cuts off whenever E_1 is greater than E_2. Thus, an a.c. signal with an amplitude of a few millivolts impressed on the first grid, through the transformer T, will appear in the output only when E_1 and E_2 are very nearly equal. This signal is used to trigger the contour printer. With a high-μ tube such as the type 12AX7, the cut-off characteristics obtained are quite sharp; the output drops to less than half its peak value when E_1 and E_2 differ by as little as 0·4 V, and falls to zero when E_1 and E_2 deviate from equality by approximately 0·8 V.

The complete gating circuit is shown in Fig. 4. Provision has been made at present for six contours covering the density range from 1·0 to 2·5, though more contours can be added if required. By inserting a neutral filter with a density of 1·0 in the scanning beam, these contours can be shifted to cover the density range from 0·0 to 1·5.

As can be seen from the figure, the d.c. output voltage from the logarithmic amplifier V_8 is applied to one grid of each of the six gating tubes (V_{11} to V_{16}) through a cath follower V_9, while bias potentials corresponding to density contours required are applied to the other gr These bias voltages are taken from a bleeder connected acr the voltage regulator tube V_{18} and can be set by means the potentiometers RV_{10} to RV_{14}.

The a.c. input is taken from a Wien bridge audio oscilla V_{10} which provides an amplitude-stabilized 500 c/s signal is fed to the first set of grids of the gating tubes by me of the transformer T_1. Whenever any of the gating tube conducting, the a.c. output from this tube appears across common plate resistor R_{32}. This is further amplified by and V_{21A} before it is applied to the output cathode follo V_{21B} which drives the argon glow lamp A in the cont printer.

Individual contours can be turned off temporarily means of the switches S_1 to S_6 for purposes of identificati while a microswitch S_7 mounted on the carriage of microphotometer automatically blanks off all the conto between successive scans.

In order to eliminate oscillations due to feedback from output cathode follower V_{21B} to the logarithmic amplifier the entire gating circuit was run from a separate power sup stabilized by two voltage regulator tubes. It was also fou advisable to insert a two-section, low-pass filter R_9C_6, R in the logarithmic circuit to cut off high frequency no from the photomultiplier, which otherwise caused flicker of the contours.

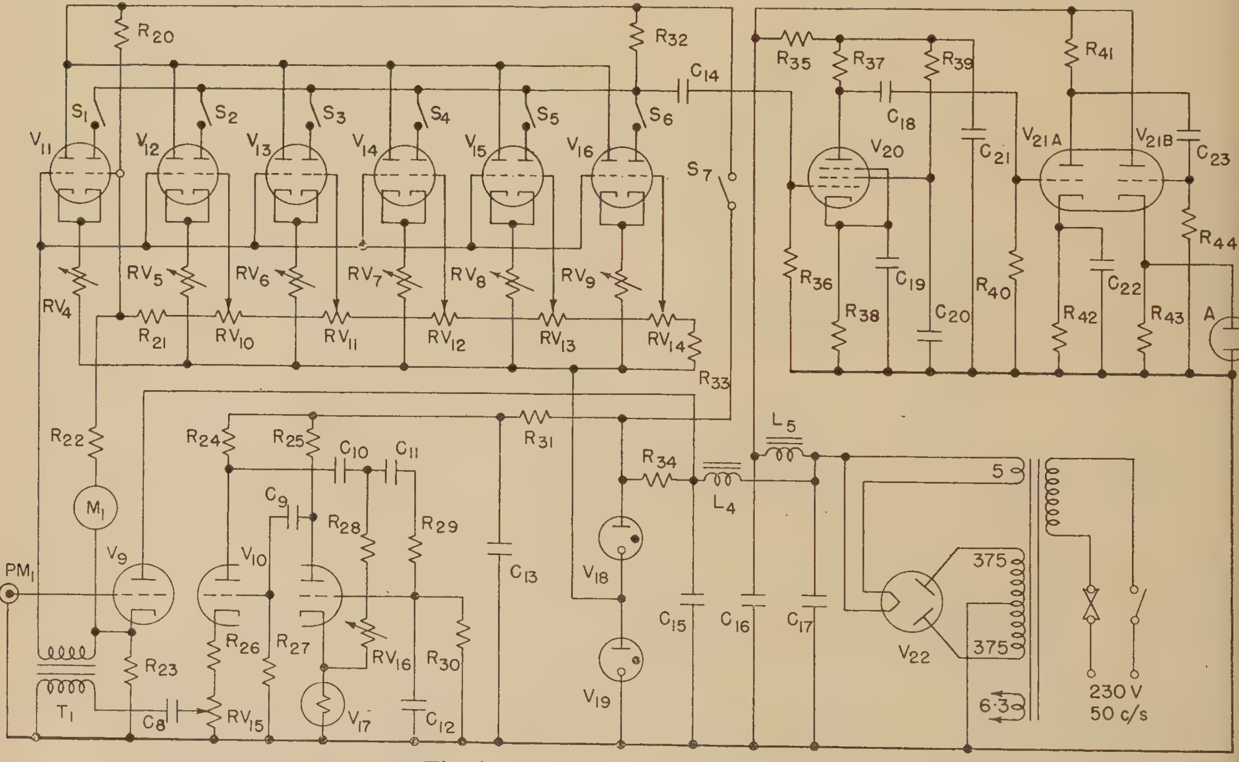


Fig. 4. Diagram of the gating circuit

All resistors are ±10%, 1 W carbon, except where otherwise specified.

R_{20} = 1·5 kΩ, w.w.
R_{21} = 250 Ω, w.w.
R_{22} = 800 kΩ
R_{23} = 33 kΩ, 2 W
R_{24} = 18 kΩ
R_{25} = 47 kΩ
R_{26} = 470 Ω
R_{27} = 1 MΩ
R_{28} = 1 kΩ
R_{29}, R_{30} = 33 kΩ

R_{31} = 10 kΩ, 5 W
R_{32} = 10 kΩ, w.w.
R_{33} = 3250 Ω, w.w.
R_{34} = 5 kΩ, 10 W
R_{35} = 22 kΩ
R_{36} = 470 kΩ
R_{37} = 100 kΩ
R_{38} = 580 Ω
R_{39}, R_{40} = 470 kΩ
R_{41} = 100 kΩ

R_{42} = 2·7 kΩ
R_{43} = 7·5 kΩ, w.w.
R_{44} = 470 kΩ

RV_4–RV_9 = 1 MΩ
RV_{10}–RV_{15} = 500 Ω
RV_{16} = 1 kΩ

C_8 = 0·1 μF
C_9 = 0·01 μF

C_{10} = 8 μF
C_{11}, C_{12} = 0·01 μF
C_{13} = 16 μF
C_{14} = 0·002 μF
C_{15}, C_{16} = 32 μF
C_{17} = 16 μF
C_{18} = 0·002 μF
C_{19} = 25 μF
C_{20} = 0·1 μF
C_{21} = 32 μF

C_{22} = 25 μF
C_{23} = 0·002 μF

V_9 = 6J5
V_{10} = 6SN7 GT
V_{11}–V_{16} = 12AX7
V_{17} = 230 V, 5 W lamp
V_{18} = VR 75
V_{19} = VR 105
V_{20} = 6SJ7

V_{21} = 6SN7 GT
V_{22} = 5Y3 GT

A = Argon glow lamp

L_4, L_5 = 8 H

T_1 = Audio transformer, 3:1 step down

M_1 = 0–50 μA meter

PRELIMINARY ADJUSTMENTS

ıe two sections of the electronic circuit were adjusted as ·ws:—

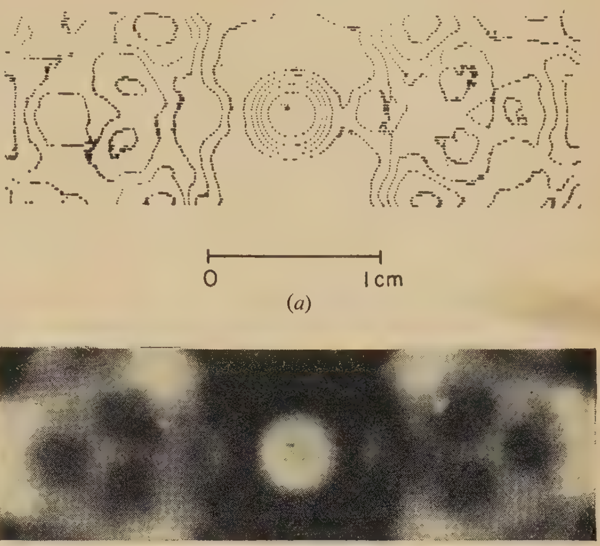
ıe logarithmic photoelectric circuit. The voltage of the) *L* in the microphotometer was initially adjusted by ns of the rheostat *R* until the dynode voltage (with a dard density of 2·5 placed at *P* in the scanning beam) 120 V per stage. After this, the potentiometer RV_1 was sted so that the meter M_1 showed zero current. Finally, density standard was removed and RV_3 was adjusted so M_1 indicated a current of 50 μA, corresponding to a ity reading of zero.

he gating circuit. The first step in the adjustment of the ng circuit was to set the bias potentiometers to correspond he desired density contours. This adjustment could be ied out either with a standard photographic neutral step ge, or by measuring the bias voltages with a high-tance test meter. The next step was to adjust the output ı all the gates to equality, when each one of them was ' conducting. This adjustment is necessitated mainly by difference in the effective plate voltages applied to the ng tubes and can be conveniently carried out by means ıe variable cathode resistors RV_4 to RV_9 without resulting ıny change in the density levels of the corresponding ours. Finally, the a.c. signal level from the oscillator adjusted by means of the potentiometer RV_{15}, so that output voltage from the cathode follower, with the gate ducting, was about 10% more than the striking voltage he glow lamp *A* (approximately 90 V). This gave a y intense glow without resulting in any appreciable loss ensitivity in discrimination.

PERFORMANCE

ctual measurements with this instrument showed that the ng circuit was extremely stable and quite sensitive, a ıge in the density of the plate of ±0·02 from the nominal sity corresponding to any contour being enough to nguish the lamp in the contour printer. In practice, the pness of the contours obtained was found to be limited nly by local fluctuations in the density of the negative to its granularity.(1)

typical contoured density map of a negative obtained ı this instrument is shown in Fig 5(*a*) while Fig. 5(*b*) is enlargement to the same scale from the negative itself. total time taken to scan this area, 11 mm by 33 mm, with a spacing of 0·16 mm between successive scans, was a little over an hour.



(*a*)

(*b*)

Fig. 5. (*a*) Contoured density map of a typical negative. (*b*) Enlargement to the same scale from the same negative

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Dr. D. Sen for his assistance in this work, and to the Director, National Physical Laboratory of India, for permission to publish this paper.

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Laboratory and workshop notes

'hotoconductive detector of radiation of wavelength greater than 50 µ

;y S. J. FRAY, and J. F. C. OLIVER, Royal Radar Establishment, Great Malvern, Worcestershire

[*Note received* 13 *October*, 1958]

s well known that Group V elements are soluble to some ent in germanium and that an electron associated with h atom of such impurities has an excitation energy to the duction band of about 0·01 eV. This energy is the same hat of a photon of radiation of 124 μ so that specimens of manium "doped" with suitable concentrations of these ourities should show photoconductivity to infra-red radiaı of long wavelengths, provided the specimen is sufficiently l for the donor level to be occupied.

A detector has been made of germanium doped with antimony (2 Ω-cm at room temperature) and was demonstrated during the Physical Society's Conference on "Spectroscopy of solids" held in May 1958 at Malvern. The detector is mounted inside a brass thimble and both are cooled in a liquid helium bath. In this way the element is screened from most of the stray radiation and thermal excitation is small. Wanted radiation is admitted to the element through a window of crystal quartz in an outer vacuum case at room temperature and a window of fused quartz at 4·2° K let into the base of the metal helium bath. A shield at liquid nitrogen temperature protects the helium from excessive evaporation loss, but the wanted radiation passes through a hole in the shield and there is no window at this temperature. In the present detector the resistance of the element at 4·2° K is 500 000 Ω when fully shielded, but is considerably lower due to stray radiation when mounted for operation.

A modified Leiss monochromator⁽¹⁾ (Fig. 1) has been used to examine the performance of the detector. Short wave radiation from a globar source at about 1 500° C is scattered by a rough mirror m_2 and the long wave radiation passes through a sooted quartz filter at the slit S_1. Further scattering and filtering occurs at the sooted plane aluminium mirror m_3. The dispersing element is a brass echelette grating G engraved with 250 lines per inch and blazed at 80 μ in the first order.

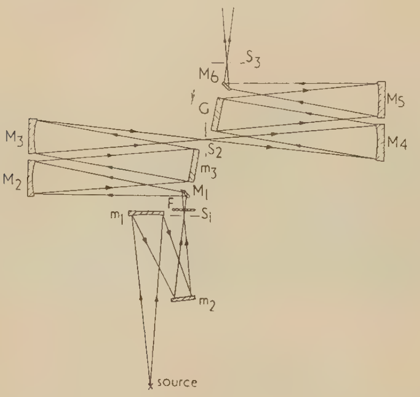

Fig. 1. Optical schematic of Leiss Double monochromator as modified for use in the far infra-red

M_2, M_3, M_4, M_5	concave mirrors, 57 × 55, $f = 300$
M_1, M_6	plane mirrors, 25 × 27
m_1	concave mirror, 60 × 60, $f = 150$
m_2	plane mirror, 44 × 48, with front surface roughened
m_3	sooted plane mirror, 57 × 57
G	echelette grating
F	sooted quartz filter
	(Units in mm)

The monochromator is alined with visible light before the mirrors and filter are sooted and the position of the grating for zero order is found by placing a plane front-aluminized mirror on the front surface of the grating. The output of the monochromator can be directed either to the photo-detector or to a Golay cell fitted with a crystal quartz window, so that the performance of the two detectors can be compared. Fig. 2 shows recordings by the two detectors of the rotational spectra due to residual water vapour in the spectrometer. The calibration of the wavelength scale is not of high accuracy but the spectrum compares well with that given by Lord and McCubbin.⁽²⁾

The radiation was chopped at 5 c/s when detecting with the Golay cell and at 800 c/s when using the photo-detector, and the detected signal passed through an integrating circuit with a time constant of 2 s. The gains of the amplifiers were adjusted so that the noise was roughly comparable in both recordings and the radiation falling on each detector was varied by altering the centre slit S_2 so that the detected signal comfortably filled the recorder chart. All other conditions were identical. The width of the slit S_2 was 3 mm when the Golay cell was used and it is estimated that the radiation covered an area of 3 mm² of the cell window. The slit was set to 1 mm when receiving with the photo-detector of area approximately 10 mm².

The sensitivity of the Golay cell is uniform from the visible to the near microwave region so that the spectrum of Fig. 2(*a*) gives a measure of the distribution of power from the monochromator with wavelength. The photo-detector, on other hand, is most insensitive at 50 μ and increases in se tivity at the longer wavelengths. Further prelimi measurements show that the element is photoconductive t least 118 μ. No measurement of the speed of response yet been made but the detector is expected to be very f ($\tau < 10^{-5}$ s). Further, it is doubtful if the detector alrea made is being used under optimum conditions.

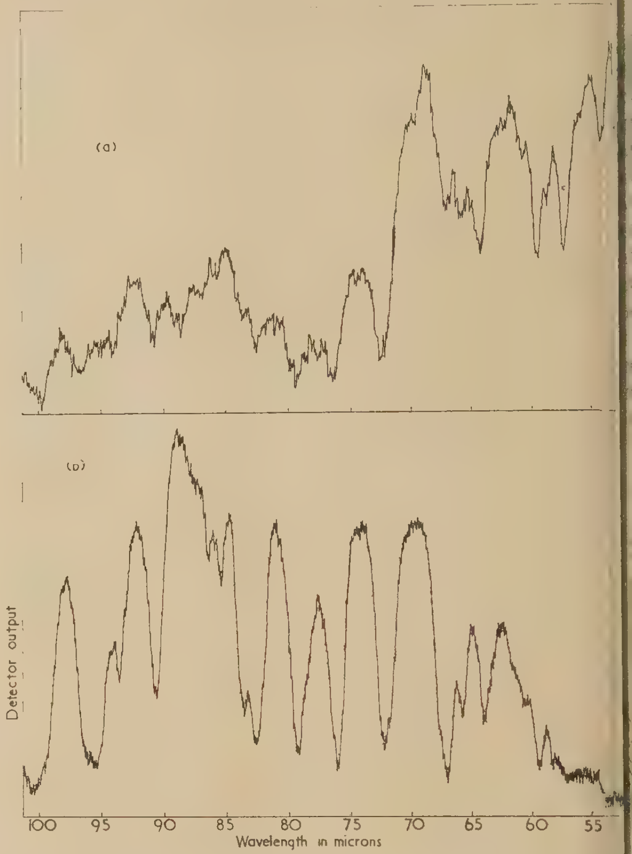

Fig. 2. Rotational spectrum of water vapour betweer 55 and 100 μ

(*a*) Golay detector; (*b*) Photoconductive detector

It is intended to use the detector for cyclotron resonan measurements in semiconductors with infra-red radiation a magnetic fields up to several hundred kilogauss. Measureme similar to these have already been made by R. J. Keyes *et al.* who used a cooled zinc-doped germanium detector at wav lengths between 10 and 22 μ.

The authors are indebted to Dr. J. M. Lock for some of t initial work, to Mr. P. J. Hoyland who grew the crystal fro which the specimen was cut and to Dr. D. H. Parkinson f many helpful discussions and encouragement. Acknowledg ment is made to the Controller, H.M. Stationery Office, f permission to publish this note.

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Simple evaporator for radioactive metals

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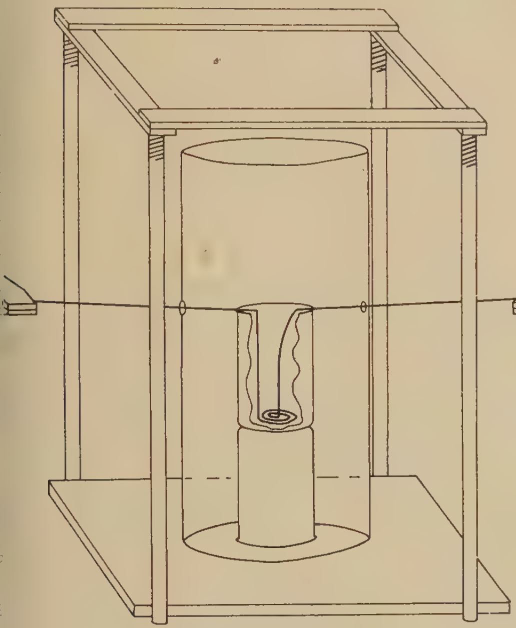
of Edinburgh

[*Note received* 24 *October*, 1958]

nple device for the vacuum evaporation of radioactive
rials, for tracer purposes in metallurgy, has been de-
ꞁed in this laboratory. The method restricts the active
orant to a cheaply and easily replaced evaporation vessel
n may be scrapped after a single evaporation, if this is
able.

rewed rods soldered into each corner of a brass plate
t 10 cm square are used to support rails 10 × 1 × ¼ cm
height of about 10 cm above the plate. The brass plate
vered by a lantern slide cover glass on which stands an
-ended glass tube, 5 cm in diameter and 10 cm long,
two diametrically opposite holes, about 4 mm in
eter, blown in it at about 5 cm from one end. An
ina crucible type XN 5 (by Morgan Crucible Co. Ltd.)
m high and 1·5 cm diameter, is placed on a stand



Arrangement of evaporator

ther similar crucible) inside the glass tube so that its
s level with or slightly higher than the two holes in the
A 0·5 mm diameter tungsten filament wound into a
piral as shown, is placed inside and close to the bottom
e crucible with the lead wires coming through the holes
e glass. The active evaporant is dropped into the
ble and evaporated by radiant heat from the filament.
ecimens are supported above the glass tube by the rails
a cover glass above them collects stray evaporant. It is
d that the deposit is fairly uniform over the area of the
mens and that about one fifth of the active material is
sited on this area. The remainder is on the wall of the
ble.

is method of evaporation has the advantages that there
contamination of the bell jar and other accessories, and
the radioactive handling is reduced to a minimum since the evaporant needs no careful placing in the filament. We have successfully evaporated copper, gold and antimony using this technique. No traces of activity have ever been detected outside the active enclosure, on the glass plate below the crucible or on the filament.

Method for operating a galvanometer amplifier from a low resistance input circuit

By G. G. E. Low, Naval Research Laboratory, Auckland
NI, New Zealand

[*Note first received* 3 *October, and in final form*
18 *November*, 1958]

In order to secure satisfactory operation when using a moving-coil galvanometer in a low resistance circuit it is necessary to introduce a series resistor of a value equal to the critical damping resistance for the galvanometer. As this resistance is usually at least an order of magnitude greater than the resistance of the galvanometer itself, a considerable loss in voltage sensitivity is brought about. Another method that is sometimes employed for adjusting the damping of a galvanometer is to reduce the field (H) in which the galvanometer coil moves by linking the poles of the magnet with a shunt. The current sensitivity of a galvanometer is proportional to H whereas the magnetic damping (and thus the critical damping resistance required) varies as H^2, so that by diminishing H an improved voltage sensitivity corresponding to the condition for critical damping may be obtained. Nevertheless voltage sensitivity is sacrificed in order to obtain proper damping conditions.

The purpose of the present note is to describe a simple method for controlling the damping of a galvanometer in a galvanometer amplifier system, which involves no loss of sensitivity. This method is based on the use of feedback. That the input characteristics of galvanometer amplifiers may be improved for certain applications with the aid of negative feedback signals which are proportional to but out of phase with the angle of galvanometer deflexion (θ) is well known (see for example Frankenhaeuser and MacDonald(1)). Such feedback, however, is equivalent to an increase in the magnitude of the restoring torque constant and any improvement in operation secured by this means is always accompanied by a loss of sensitivity. A feedback signal which is proportional to $d\theta/dt$, on the other hand, may be used to counteract directly the back e.m.f. arising from the motion of the galvanometer coil in the magnetic field and in this way improved response times for low resistance input circuits may be obtained without any loss of sensitivity. It is this principle upon which the present method of damping control is based. Feedback of this latter type has also been considered by Schmitt.(2) In the system he describes, the feedback current is derived from the charge on a capacitor in the output of a valve voltage amplifier which follows the photo-sensitive elements. In the present method a small transformer provides the feedback signal and it is suggested that for certain applications this method may have the advantage of simplicity.

The system used is as follows. From the output of the galvanometer amplifier a current proportional to θ is passed through the primary winding of the transformer. The secondary of the transformer is connected in series with the galvanometer and in such a sense as to provide positive feedback, so that the e.m.f. developed in this winding (proportional to $d\theta/dt$) counteracts the e.m.f. in the galvanometer coil arising from movement in the magnetic field. We may write the equation for the motion of the galvanometer as,

$$I\frac{d^2\theta}{dt^2} + \beta\frac{d\theta}{dt} + k\theta = \alpha i_g$$

where I is the moment of inertia of the coil assembly, β is the air damping coefficient, k is the restoring torque constant, i_g is the galvanometer current and α is the product of the number of turns and the area of the galvanometer coil together with the magnetic field in which the coil moves. Also we have in the galvanometer circuit that

$$e = Ri_g + \alpha\frac{d\theta}{dt} - \frac{A}{S}M\frac{d\theta}{dt}$$

where e is the signal voltage, R is the total resistance in the circuit (including that of the galvanometer), A is the current gain of the amplifier, S is the sensitivity of the galvanometer in radians per unit current and M is the mutual inductance between the windings of the transformer. The effects of the self inductances of the windings on their respective circuits have been neglected and so also has the voltage induced in the primary circuit by the small current i_g passing throught the secondary winding. Under the conditions of critical damping these approximations are valid if

$$R \gg L_2/\tau,\ R_1 \gg L_1/\tau \text{ and } R_1 \gg M/A\tau$$

where L_1 and L_2 are the self inductances of the primary and secondary windings respectively, R_1 is the total resistance in the output circuit of the amplifier (including internal resistance) and τ is the time constant associated with the damping. In general these conditions can be met by the use of a suitable step-down transformer.

On eliminating i_g from the above equations we have that

$$I\frac{d^2\theta}{dt^2} + \left(\beta + \frac{\alpha^2}{R} - \frac{\alpha AM}{SR}\right)\frac{d\theta}{dt} + k\theta = \frac{\alpha}{R}e$$

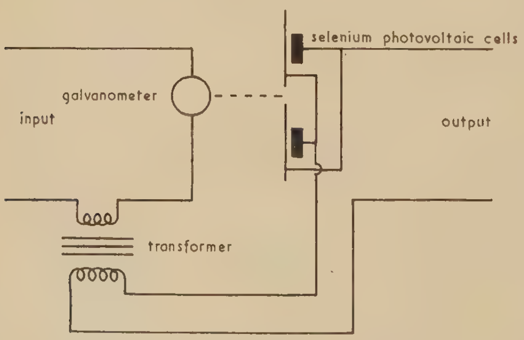
Hence for critical damping it is necessary that

$$M = \frac{SR}{\alpha A}\left(\beta + \frac{\alpha^2}{R} - 2k^{\frac{1}{2}}I^{\frac{1}{2}}\right)$$

$$\doteq \frac{\alpha S}{A}$$

as the term corresponding to magnetic damping is considerably larger than the other terms on the right hand side for a low resistance input circuit.

The method of damping control described above has been used conveniently in connexion with an amplifier system consisting of a Tinsley type 4500 galvanometer (10 ohm) and a pair of selenium photo-voltaic cells (current gain of about 60). A transformer whose primary consists of some 5000 turns of 40 s.w.g. enamelled wire wound on a small mumetal E-c is connected as shown in the figure. It was found that, w the resistance in the input circuit is virtually that of galvanometer alone, a 16-turn secondary winding gives correct coupling for critical damping. This correspond a mutual inductance of about two and a half H which i reasonable agreement with the value calculated from expression given above. When using a transformer in manner in a circuit containing a galvanometer it is, of cou necessary to shield it carefully from fluctuations in external magnetic field. It was observed that when coupling through the transformer was increased to the p where oscillations occurred that the period of these oscillati was considerably longer than that of the free oscillation the galvanometer. This effect was attributed to lag introdu by the selenium cells between the current in the primary the transformer and the deflexion θ. Such lag would rise to an e.m.f. component in the secondary winding wh would be proportional to θ and would thus be equivalent reduction in the value of k, with a consequent decrea frequency of oscillation.



Simple galvanometer amplifier using the feedback damping control described

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(2) Schmitt, O. H. *J. Sci. Instrum.*, **15**, p. 234 (1938).

Growth of uniform circular cylindrical crystals of predeterm orientation

By E. V. Vernon, Ph.D., A.Inst.P., Physical Laborato
The University, Southampton

[*Note received* 30 *September*, 1958]

The investigation of many of the physical properties anisotropic metals is facilitated by the use of specimens the form of single crystal rods of known crystallogra orientation. The techniques for the production of s specimens are well known, but it is extremely difficult obtain single crystal rods of accurately uniform (prefera circular) cross-section, which is an essential requirement the measurement of the elastic moduli by the resona method, and of the electrical resistivity. An arrangem suitable for the growth of circular cylindrical single crystal indium, tin, and zinc which has proved most successful should equally well apply to other low melting point metal as follows. The crystals are grown by the method of c trolled solidification from the melt and a travelling furna similar to that originally used by Andrade and Roscoe,* travelling either vertically upwards or up an incline, is us The Pyrex glass mould in which the metal is crystallized c sists of two similar semi-circular troughs, carefully grou from two similar precision bore tubes (we are indebted Messrs. C. J. Whilems for grinding the troughs). The troughs are held tightly together by spring-loaded stain steel clamps placed at intervals of about 6 cm along the mou Fig. 1 shows the arrangement and the method of support the seed crystal, which is used when a crystal of a partic orientation is required. Before insertion in the mould metal is cast in rod form; the diameter of the rod is sligh less than the internal diameter of the mould in order prevent stresses being developed at the liquid/solid interf during the crystal growth. When a seed is not used, lower end of the mould is blocked by a graphite plug. Fig

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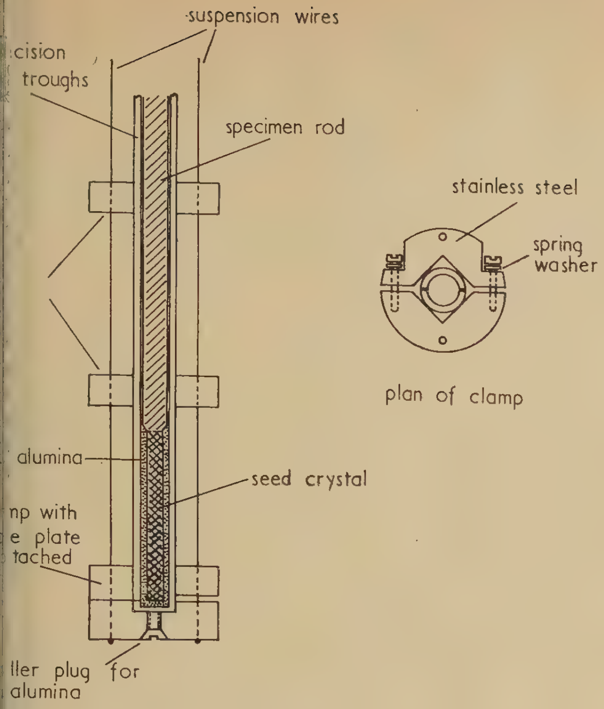
* Andrade, E. N. da C., and Roscoe, R. *Proc. Phys.* (*London*), **49**, p. 152 (1937).



g. 1. Arrangement and method of support of seed crystal

trates the uniformity attained in the growth of the single al rod.

Tin crystals, 250 mm long and 6 mm diameter, of orientations 0° and 90°, have been successfully grown. The 90° crystals, however, show some imperfection, particularly lineage, but this is believed not to be due to the constraint of the mould, as crystals, grown horizontally in open moulds have exhibited similar imperfections. The moulds used for indium were coated internally either with a thin film of colloidal graphite or a thin film of "Fluon" to prevent attack of the glass by the metal. The film was obtained by using the Imperial Chemical Industries "Fluon" dispersion GP1.

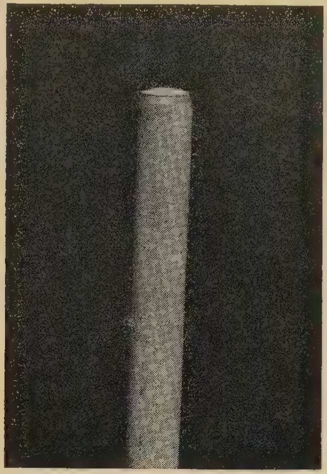


Fig. 2. Specimen showing uniformity of growth attained

Correspondence

Recording optical lever

writers regret that an error occurred in their paper which published under the above title in the February issue of *Journal*. The first part of the last sentence on p. 94 ld read: "The sensitivity . . . of the order of 30 microns/ m;". "30 microns/century" is incorrect.

ral Philosophy Department, R. V. Jones
versity of Aberdeen J. C. S. Richards
[24 February, 1959]

Comments on the A.S.T.M. Powder Data File—4

writers have now prepared a fourth booklet, bearing the ve title, which contains further additions to the lists iously published and described in The Institute's journals.* Copies of the present booklet have been distributed in the same way as were the others. Those who have not received copies of the booklet in this way may obtain them (free of charge) on request from The Institute or from us.

It is hoped that similar lists of comments will be published at approximately annual intervals. Users of the Data File are urged to send to the writers any material that they feel should be included in future issues.

Viriamu Jones Laboratory, J. W. Hughes
University College, Cardiff, Isabel E. Lewis
Great Britain. A. J. C. Wilson
[8 January, 1959]

* Hughes, J. W., Lewis, Isabel E., and Wilson, A. J. C. *Brit. J. Appl. Phys.*, **9**, p. 123 (1958); *J. Sci. Instrum.*, **35**, p. 120 (1958).

NOTES AND NEWS

New instruments, materials and tools

reep resisting alloy. Henry Wiggin and Co. Ltd., Wiggin Street, Birmingham 16.

s alloy, Nimonic 105, of nickel-cobalt-chromium and ybdenum is a development from a previous alloy made the firm. It is claimed that it has greater resistance to p at very high operating temperatures than the previous , the minimum life to rupture at 7 ton/in.^{2} and 940° C 24° F) being 50 h.

An important advantage of the alloy is said to be its improved resistance to a specific type of high-temperature corrosion sometimes experienced in aero and other gas turbines running at elevated gas temperatures. This corrosion occurs in certain conditions of contamination by solid or molten sulphates associated with the combustion process. The fuels used in this temperature range are high-grade distillates, such as aviation kerosene, which at lower temperatures have little or no corrosive effect. It will be appreciated that this form of high-temperature corrosion is quite different from the fuel-ash corrosion troubles met at much lower temperatures when certain types of boiler oils are burned in gas turbines.

The alloy has already been tested by the British aero-engine industry and is now in production.

High speed rotary switch. Vactric (control equipment) Ltd., Vactric House, Sloane Street, London, S.W.1.

The switch has been designed to fulfil many of the requirements of remotely operated systems. It is claimed to have already solved many of the problems usually associated with telemetry work and is finding considerable use in such diverse applications as d.c. signal chopping, wave-form generation, amplifier stabilization, low-level sampling of strain gauge and thermo-couple signals, digital counters, and in other high speed or low speed applications where information is sampled.

The makers state that its construction permits it to be one of the smallest of its kind and that care has been taken to extend the life of the switch without maintenance and without the use of oil baths, etc. Wiper pressure is low, compatible with contact wiper bounce, and because of this, several leads may be ganged together on a common shaft. In high frequency systems where intercoupling between channels is difficult to eradicate, this type of switch provides the minimum possible coupling between segments. Segments may be inter-connected to provide a large variety of the "on" to "off" time ratio, or if so desired, special track configurations will be considered. Leads are supplied plain or can be screened, and in either case they are left free for attachment to the user's terminal block.

Two examples of the switch are (*a*) a 24-way low speed switch, driven from a 6 V d.c. motor *via* a precision 80 : 1 reduction gearhead and (*b*) a 24-way high speed switch driven directly at motor speed, which in this case is approximately 6000 rev/min.

The different switches may be connected by means of suitable gear systems.

The noise level is said to be about 100 μV for 1·5 mV signal for the full life of the switch, and the timing accuracy about 10 min of arc; the speed is up to 12000 rev/min and the power consumption is about 2 W. The life is over 200 h at 6000 rev/min, and considerably extended at lower speeds, when a greater noise level can be tolerated. The mounting may be made to suit the user's requirements.

γ-ray electrometer. Electronic Instruments Ltd., Lower Mortlake Road, Richmond, Surrey.

The instrument is intended for measuring the concentration of uranium ore in a slurry. The measurement has to be made whilst the slurry flows through a steel pipe in an ore treatment plant. The absorption of the γ-rays in the pipe varies with the density of the slurry. This change in absorption, howe is small compared with the total γ-ray flux incident on ionization chamber. Therefore, an instrument is requ which will measure a small change in the presence of a la signal.

The electrometer is designed around an electro-mechan device which replaces the electrometer valve and whic said to provide a far higher degree of sensitivity and stab than can be attained by conventional valve circuits.

Electric stop clock. Electrical Remote Control Co., L Harlow New Town, Essex.

This clock can be energized, stopped and reset fro distance. Its main application is the indication of elap time in process control, research, etc. The clock incorpora a synchronous motor driving, through an electromagn clutch, a pointer on a dial. The synchronous motor can running continuously, but the pointer commences its tra in a clockwise direction from the moment of energiza of the electromagnetic clutch coupling the motor to pointer.

De-energization of the electromagnetic clutch alw resets the pointer to zero position within half a second. T electromagnetic clutch of the timer can be operated b voltage different from the supply to the motor of the cloc

The clocks operate on single phase a.c., between 50 60 c/s, and d.c./a.c. conversion units can be supplied operation on d.c. They range from a full-scale reading 30 s, to one of 120 h, and their dimensions are approximat 5 × 5 × 7 in.

British Journal of Applied Physics

Contents of the April issue

CONFERENCE REPORT

Summarized proceedings of a Conference on solid state memory and switc devices—London, September, 1958. By T. B. Rymer.

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Unifying design principle for the resistance network analogue. By F. C. G

Effect of deformation of the surface texture on rolling resistance. By J. Halli

Use of an electronic analogue computer with resistance network analogues. J. Ph. Korthals Altes.

Analysis of a polydisperse aqueous spray from a high-speed spinning atomizer. By D. J. Ryley.

Excitation and ionization rates of mercury in discharge plasmas. By M. Cayless.

Analysis of the lighter elements by total reflexion of their characteristic X- wavelengths. By A. Franks and R. F. Braybrook.

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On the use of coarse gratings in ultrasonics. From G. M. Sreekantath.

Comments on the A.S.T.M. Powder Data File—4. From J. W. Hughes, Isa E. Lewis and A. J. C. Wilson.

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SPECIAL ARTICLE

The Physical Society's Exhibition—London, 1959

By R. V. JONES, C.B., C.B.E., F.Inst.P., F.R.S.E.

A general survey is given of the newer developments of instruments and apparatus exhibited, together with some observations on the Exhibition and the prize list of the Craftsmanship and Draughtsmanship Competition.

INTRODUCTION

Physical Society's 43rd Exhibition of scientific instru-
ts and apparatus was held from 19 to 22 January, 1959,
he Halls of the Royal Horticultural Society. The 42nd
ibition had taken place only ten months earlier, and this
helped to emphasize the impression gained from previous
bitions that a year is a comparatively short time in the
elopment of a modern scientific instrument. Indeed,
y of the instruments that were quite justifiably shown
year had already appeared in earlier forms in previous
s. It is also true that several of the items that were new
this year's Exhibition had been anticipated abroad,
bly in the United States. It is nevertheless good to see
n, and to know that they are now on the British market;
it is not altogether a valid criticism of British manu-
urers that they should have adopted techniques and
ruments developed abroad. We cannot expect to have
e than our share of the world's original ideas, and we
ld be foolish if we did not take up good ideas, whatever
r source. Having said that, however, one might still feel
et that some manufacturers seem to lean rather too
vily on overseas developments, with the result that we
lag unduly, in some fields, behind foreign competitors.
his connexion, some exhibits from abroad, particularly
nstruments which have no British equivalents, would be
cially valuable. These could hardly jeopardize the
spects of our own manufacturers, and the present high
e of the Exhibition would be enhanced by showing how
range of instruments available to the British user from
home industry may be supplemented. While this sug-
ion might be difficult to implement fully, The Physical
iety is to be congratulated on its practice of inviting
ibits from particular countries; this year the Royal
dish Academy of Engineering Sciences accepted an
tation to sponsor some exhibits.

bjectives. It would be unwise to adopt too doctrinaire a
vpoint regarding the object of the Exhibition. It might
counsel of perfection to demand that every item shown
uld incorporate a new idea, but it ought to be admitted
many of us who go to the Exhibition do so at least
tly with the objective of seeing what instruments are
ently available. Provided that the showing of new
ruments is not hindered by the space occupied by older
ruments, there can be little objection to the older instru-
its appearing, if they still represent the best available.
reover, while the exhibits are an important factor, the
ibition is itself an occasion; for many of us it is a reunion,
an opportunity for discussing problems of instruments
techniques with the men on the stands. The Physical
iety's Exhibition must be among the highest for the
fessional competence and enthusiasm of the exhibitors,
the Society is wise in not adopting too rigorous a policy
ut the exhibits themselves.

Looking back. It is an exhilarating, even if tiring, experience to man a stand. I myself had a stand at the 1934 Exhibition, and I still have the catalogue for that year. It is interesting to compare the two Exhibitions separated by twenty-five years: the predominant contrast is the decline in the number of University stands, and the rise in those manned by Government establishments. The figures for the two years are:—

Year	*Trade manufacturers*	*University physics departments*	*Government establishments*
1934	81	11	3
1959	133	0	22

The Universities. The University representation has declined steadily since World War II. Ten years ago, one might expect to find five or six Universities among the exhibitors; and of the forty-three Exhibitions that have so far been held, this year's is probably the first in which no University physics department has been represented. This is a melancholy sign: it is worth further consideration.

Few physics departments can afford the effort to man a stand, particularly in term time, and in many instances they are not concerned with the production of instruments or techniques in a sufficiently finished state for exhibition. But beyond these factors it is starkly evident that the Universities are lagging behind the better Government establishments through the teaching load on the academic staff and through the paucity, both in numbers and in pay, of the supporting technical staff in the Universities. While it may be inappropriate to labour the point here, the 1959 Exhibition has underlined the dangerous position to which University physics departments have been forced by the trend of national policy.

At the same time, a University observer must congratulate the Government establishments on the general high level of interest of their exhibits. Some of those at the 1959 Exhibition were particularly good, and will be mentioned later.

THE EXHIBITS

While an attempt to review the Exhibition is not to be compared with the feat of the late C. K. Ogden in successfully reviewing the *Encyclopedia Britannica*, it is difficult to do justice to the many instruments and ideas displayed in the Exhibition. Inevitably, any one reviewer will be more appreciative of instruments in fields with which he has been himself associated, and it is hoped that some of the shortcomings of the present review will be ascribed to this fact.

Materials. One valuable function of the Exhibition is to bring to the notice of the physicist the new materials and components on which the advancement of technique depends. It may need a personal acquaintance with the problems of developing a new material to appreciate fully the achievement that an exhibit represents, since the material itself rarely makes a spectacular exhibit. By any standards, however, it was impressive to see the high quality optical glasses made by the new continuous process of the Chance–Pilkington Optical Works, and the gamma-ray shielding window weighing 1200 lb produced by the same firm. In the same category, an optical material of great interest was the very high purity fused silica, Spectrosil, made and shown by the Thermal Syndicate Ltd.; this material is now being produced in a comprehensive range of components from ultra-violet prisms transmitting down to 1650 Å to crucibles for the preparation of semiconductor materials.

The metallurgical exhibits maintained their usual interest. The techniques of Murex Ltd. in the working of refractory metals such as tungsten, molybdenum and zirconium were noteworthy; this firm also showed a machinable sintered permanent magnet alloy, Comalloy, with a BH_{max} of about 10^6 gauss-oersteds. One of the most interesting magnetic materials was the Supermumetal of the Telegraph Construction and Maintenance Co. Ltd.; this is a soft magnetic material of initial permeability 70 000–80 000, maximum permeability 230 000 to 350 000, and hysteresis loss 7 erg cm^{-3} $cycle^{-1}$. Among electrical resistance materials, Johnson Matthey and Co. Ltd. showed an extensive range of noble metal alloy wires of diameters down to 12·5 μ, and a new composite resistance wire of the well-known Minalpha alloy with a sheath of another alloy to produce a compensated wire with a resistance change of not more than 150 parts per million between 0° C and 100° C. A useful thermocouple material was shown by Engelhard Industries Ltd.; in principle the thermocouple wires are sheathed inside a flexible metallic tube packed with refractory oxide powder. Twin core material has an external diameter of about $\frac{1}{16}$ in.; single core material, in which the sheath forms the second metal, may have a diameter down to $\frac{1}{32}$ in.

Graphite is a valuable material for applications ranging from nuclear reactors to crucibles for crystal growing. While impermeable graphite is not available in Britain in the larger sizes that are made in the United States, it is good to see British potential improved in this respect by the development of processes for rendering porous graphite impermeable by impregnating it with carbon compounds which are then decomposed by heating. The Royal Aircraft Establishment and the General Electric Company showed specimens impregnated by their independent processes.

Semiconducting elements and compounds of high purity are becoming generally available. The Plessey Company, whose stand included many materials and components, showed indium antimonide and several other semiconductors. Very pure silicon was shown by Standard Telephones and Cables and by the General Electric Company.

The "messiness" of immersion oil for microscopes has been reduced by Cooke, Troughton and Sims, Ltd. The tendency for the oil to spread has been eliminated by the development of a thixotropic medium of suitable refractive index which gets when left at rest at room temperature but which becomes fluid when disturbed. This material, which represents a very neat solution of a standard nuisance, was shown at the Exhibition.

Components. The Plessey Company and Ferranti Ltd. both showed silicon photocells of the type developed in the United States for solar electrical generators. These cells have conversion efficiencies of the order of 13%; and, since they utilize single crystals, they are likely to have more reproducible qualities than the older types of polycrystalline photocell. They can be made in a wide range of sizes, w areas from a few square millimetres to a few square inch and multiple cells are available. Each cell will give up half a volt, and the response time is of the order of a f microseconds. One of the firms was good enough to se the author samples after the Exhibition, and these were fou to perform very well in a small optical lever amplifier; sensitivity was such that cells of about 4 mm^2 area co replace iron-selenium cells of 10 cm^2 area. The opti lever with silicon cells and 3 W light source gave a bet performance than was possible with the much larger iro selenium cells and a 48 W light source.

Among optical components, the interference filters sho by Sir Howard Grubb, Parsons and Co. Ltd. were impressi These filters, which are produced by a procedure develop at Manchester University, combine high peak transmissi (up to 90%) and narrow bandwidths (down to 50 Å h value).

Very high-speed electric motors were shown by the Ato Weapons Research Establishment. These are capable rotating mirrors $2\frac{1}{2}$ in. long and $1\frac{1}{4}$ in. diameter at speeds to 200 000 rev/min, and are induction motors with solid st rotors and ferrite cored stators, with either ball race flexibly mounted plane bearings.

The Hymatic miniature air liquefier (shown on t Physical Society's Low Temperature Group stand) uses t Joule–Thomson effect, and is based on a design of the Ro Radar Establishment. Liquefaction is effected within abo 3 min directly from normal compressed air cylinders 120–300 atm. The liquefier is about 4 in. long by less th $\frac{3}{4}$ in. diameter; it will make available small supplies of liq air for such purposes as the cooling of infra-red detector circumstances where the normal methods of supply may The device is an item of skilful engineering by both t Establishment and the firm.

Automatic measurements. There were at least a doz stands showing the applications of "digitizers," which a devices producing direct numerical readings in place of pointer-and-scale indications hitherto customary in scient instruments. The commonest type of digitizer uses a sca with a coded pattern which is "read" by photoelectric mear a typical reading accuracy on a digitized voltmeter is 0·5 full scale, with readings being delivered about twenty tim per second. Along with digital reading, transistorizati had been fully applied to a self-balancing potentiomet developed by Ericsson Telephones Ltd. and the Royal Rad Establishment, resulting in a voltmeter of 1 s response tin with full scale reading of 9·99 mV, and an accuracy 0·1%. A new type of digitizer based on electromagne induction was shown by the Research Laboratories of t General Electric Company.

Moiré Fringe techniques have continued to make headw in the past year. Besides the linear measuring system show this year by Ferranti Ltd. and the circular Moiré Fring shown last year by Hilger and Watts Ltd., there have no appeared the circular and spiral Rodolite gratings develop by J. Dyson and shown at the 1959 Exhibition by Associat Electrical Industries Ltd. These gratings have been appli to alinement measuring devices; the example shown had range of 20 ft, and defined a straight line over this range within 0·0001 in. throughout.

Transistor applications. Transistorized power suppli were among the most numerous of all the exhibits; typicall they would provide stabilized d.c. maximum outputs fro 0·25 to 30 A at maximum voltages ranging from 6 to 3 from the standard a.c. mains. R. B. Pullin and Co. Lt ved a supply providing 5 W at 400 c/s for small servo ms from either 28 V d.c. or 50 c/s a.c. mains.

particularly good example of transistor application was Rank Cintel universal counter timer. This instrument its events per unit time or measures the time between ts; it will also total random counts and act as a frequency dard. The time intervals involved may lie anywhere in range 1 μs to 10 s, and this latter figure can be extended he use of external frequency generators. One hundred sixty-two transistors are employed; the total weight is 34 lb, and heat dissipation is so low that the reliability kely to be considerably better than would have been ible with thermionic valves.

nother good example of transistor application was a ode ray oscillograph shown by the Atomic Weapons arch Establishment, covering frequencies from 0 to Mc/s. Dawe Instruments Ltd. showed several transised instruments, including a battery-operated stroboscope h could be useful where a mains supply is not available.

athode-ray tubes. The range of British instruments in ast few years has conspicuously lacked a good high-speed lograph. At this year's Exhibition it was noteworthy several British firms had brought in American oscillohs to display high-speed phenomena, but it was also uraging to see that three British manufacturers (E.M.I., or, and Nagard) are now producing complete high-speed lographs. The frequency range of each of these instrus is about 0–50 Mc/s.

nong cathode-ray tubes, the travelling wave deflexion of Twentieth Century Electronics Ltd. was outstanding. be of this type capable of recording frequencies up to east 2000 Mc/s was used in a complete oscilloscope n by the Atomic Weapons Research Establishment. was among the most impressive instruments in the bition.

veral "memory" tubes were shown. Among the simplest ese was that of Electronic Tubes Ltd., which depends he fact that some phosphors after priming by electronic bardment will emit light only very weakly until they are ered by infra-red radiation. The idea is not new, for it suggested before World War II as a means of making rating tubes for reading radar signals through noise, t was gratifying to see it work so well. The tube shown lectronic Tubes Ltd. had held information for periods o a fortnight, the trace being invisible until the screen flooded with infra-red radiation.

high resolution tube was shown by Ferranti Ltd. This 12 000 line resolution, and has been developed for aire applications. An interesting idea for reducing the er required for c.r.t. scanning circuits was demonstrated Mullard Ltd.; "scan magnification" is achieved by a ave magnetic lens after the primary deflexion. A vefold magnification can thus be obtained, at the expense ome increase in spot width, and the resulting decrease in er required for full deflexion eases the problem of applytransistors. The G.E.C. Research Laboratories were ying an experimental c.r.t. for the same purpose; this an internal electromagnetic deflexion system and reduces nergy required for deflexion by a factor of some hundreds ompared with that normally required for magnetic xion.

acuum technique. The clatter of the valves of rotary ps has probably been the most characteristically dising noise in physics laboratories in the last thirty years. e past two or three years there have been considerable ovements in this respect, partly arising from better valve design, and partly from the use of two-stage pumps. Edwards High Vacuum Ltd. were showing a compact pump of this type of 30 l/min displacement, and similarly quiet pumps of a type shown in previous years were to be seen in several items of equipment shown by the Metropolitan-Vickers Electrical Co.

Both Edwards and Metropolitan-Vickers were showing equipment in or near a production stage which was capable of achieving vacua of the order of 10^{-9} mm of mercury. The pumping equipment in both instances is normal, and the improved performances have come from more thorough baffling, and from the development of all-metal taps and gaskets which can be baked out.

Edwards also showed the prototypes of several devices for the handling of liquefied gases, including one that will automatically maintain the level of liquid in a small Dewar flask by transferring when necessary from a larger reservoir. The same firm also exhibited an electron-beam welding apparatus, based on French work at Saclay, for the fluxless welding of metals in vacuum. This can be usefully applied to metals that would oxidize in air or would become brittle in hydrogen, and very neat welds are possible. The equipment, with its controls for handling components inside the vacuum, is necessarily rather elaborate.

Solid state physics. Mullard Ltd. showed a beautiful demonstration by which the ferrimagnetic domains in a single crystal of garnet could be made readily visible. Plane polarized light is passed through a thin specimen of crystal, and is rotated to a greater or lesser extent by the Faraday effect due to the line-of-sight component of the magnetic field of each domain. The behaviour of the domains in a crystal during a magnetization cycle can thus be followed.

Another impressive demonstration was that by the Royal Aircraft Establishment showing the infra-red Faraday effect in indium antimonide. This material continues to provide interest by virtue of its extremely high carrier mobility, which causes it to show a very large Hall effect. This effect is used in a transducer which was sponsored at the Exhibition by the National Research Development Corporation, and which has been developed at the Services Electronics Research Laboratory by I. M. Ross and C. C. Hilsum. The transducer is used to detect small displacements of an indium antimonide crystal in a non-uniform magnetic field. These displacements cause the resistance of the crystal to change, and thus disturb the balance of a bridge circuit. Linear displacements of the order of 10^{-9} cm can be detected by this device, and there is some hope of a tenfold improvement.

A very interesting semi-conductor demonstration was that by the Royal Radar Establishment (R.R.E.) of a photoconductive detector for long-wave infra-red radiation out to beyond 110 μ wavelength. For this application, very pure germanium is "doped" with a small concentration of antimony atoms; the excitation energy of these atoms is very small, being about 0·01 eV, which corresponds to a photon of about 100 μ wavelength. At normal temperatures, the antimony atoms are ionized, and so the device has to be operated at liquid helium temperatures. The antimony atoms are then unexcited, until suitable photons fall on them; the released electrons and holes give a photocurrent which is a measure of the number of photons falling on the crystal. The detector shown by R.R.E. had a response time of about 10^{-5} s, and was about ten times as sensitive as a Golay cell operating at the same bandwidth.

The promising low-noise characteristics of masers for the amplification of microwaves by stimulated emission are now well known. Much interest at present lies in solid state masers, and R.R.E. showed the equipment for a three-level paramagnetic maser using crystals such as the alums with iron as the paramagnetic ion. Another form of low-noise device is the "parametric" amplifier, which depends on the forced variation of one of the parameters (inductance or capacity) of a tuned circuit. Possible elements are, for example, a back biased silicon or germanium diode acting as a variable capacity, or a ferrite in a magnetic field acting as a variable inductance. If the selected parameter is made to vary by a subsidiary source of power at a frequency higher than that of the signal to be amplified, it is possible to arrange things so that the output signal is modulated at the beat frequency, and that there is more power in the modulation than there was in the original signal. Such an amplifier was demonstrated by the Services Electronics Research Laboratory.

Analytical instruments. Among spectrometers for the visible and ultra-violet, Hilger and Watts Ltd. showed a new double-beam recording prism instrument based on the Uvispek spectrophotometer; the new instrument incorporates an attractive flat chart recorder developed by the same firm. It is good to see instruments of this type appearing at last from British manufacturers, the first being the grating instrument, shown by Joyce, Loebl and Co. Ltd., at the 1958 Exhibition, and shown again this year with various accessories. Unicam Instruments Ltd. were showing a recording spectrophotometer for the range 189 mμ to 3·57 μ.

X-ray fluorescence spectrometers were shown by the Metropolitan-Vickers Electrical Co. Ltd. and by the Solartron Electronic Group Ltd. The latter instrument is an improvement on its 1958 predecessor in that the provision of an evacuated path now enables elements of atomic number less than 20 to be observed. Metropolitan-Vickers showed an X-ray micro-analyser which enables quantitative chemical analyses to be performed on a volume as small as one cubic micron. A fine electron probe (0·25 μ diameter) stimulates the characteristic X-radiation of any elements in the volume, and the radiation is analysed quantitatively. Nuclear magnetic resonance spectrometers were shown by the Fairey Aviation Co. Ltd. and the Mullard Co. Ltd.

Among many other analytical instruments for specific purposes, mention might be made of the Mark III Mervyn–Harwell square wave polarograph, and of the new model 23B pH meter of Electronic Instruments Ltd. The MS7 spectrometer of Metropolitan-Vickers is now in production; this instrument, which is intended for the analysis of impurities in solids, is said to be capable of detecting many elements present in no greater strength than 1 part in 10^8.

It is evident from the foregoing exhibits that the present acute interest of the physicist in high purity materials has stimulated the development of a wide range of most impressive analytical instruments for detecting very small traces of impurity. The necessarily complex and expensive nature of many of the instruments places them outside the reach of most laboratories, but the Exhibition at least provides an annual opportunity for learning what can be done, and (very welcome in the absence of something like a national analytical centre) of finding the manufacturers of analytical instruments sometimes ready to undertake trial analyses to help the impecunious enquirer.

Miscellaneous demonstrations. The National Physical Laboratory provided an instructive demonstration of simulated learning from experience by a computer. The computer records in a yes-no manner the occurrence of five arbitrarily chosen events; it counts how often each event occurs, and how often each possible conjunction of events occurs. From its records, the computer calculates, when any set of events occurs, the conditional probability of the ot events, assuming that the future will be like the past. T computer simulates many of the phenomena of learning animals, and can "learn," for example, how to make a trol follow the boundary between a black and a white a irrespective of whether the black is to the left or right.

Among mechanical demonstrations, the new applicatio of pneumatics to instruments by the British Scientific Resear Association were notable. One of these is a pneumatic c follower which almost entirely obviated the usual frictio force between a cam and its follower.

A simple and elegant device for facilitating particle s analysis was shown by the Pneumoconiosis Research Unit the Medical Research Council. In principle a 50 c/s vibrat mirror is inserted into a microscope so that it translates image as seen through the eyepiece. The light source flashed on only when the mirror is at its extreme positio and so two mutually displaced images are seen in the fie If the mirror's amplitude is set to produce, say, a displa ment equivalent to 10 μ in the object plane, then the t images of any one particle will overlap or not according as diameter is greater or less than 10 μ. This is a condi that can be very easily detected by the eye, and so ra analyses are possible.

CONCLUSION

The 1959 Exhibition had a record attendance of more th 26 500. The strain of limited space was at times evide but the Exhibition Committee is to be congratulated on smooth running of the Exhibition, and it well deserves thanks of all physicists for undertaking the large amount work that is entailed.

While in this review I have, in places, been critica British manufacturers, I should like to record three exam of outstanding courtesy shown by exhibitors. In the fi instance, I raised a query at one stand about the mechani details of a spectrophotometer. Less than twenty-four ho later a blueprint of the constructional drawings was on desk, the exhibitor having telephoned his works in the no of England, and the works having immediately posted blueprint to Aberdeen. In the second instance, within week of the Exhibition another exhibitor had sent me t free samples of silicon photocells to see whether they we suitable for my purpose. In the third, a firm with whom had raised an awkward problem of temperature measu ment wrote to me within a fortnight to say that they thoug that none of their products was suitable, but that one another firm might be. They had made contact with t other firm, and had ascertained the name of the man whom I should write. In none of the three instances did t exhibitors know that I was to produce this review. If the services are typical of what our manufacturers are prepar to give, the future of British scientific instruments is brig

CRAFTSMANSHIP AND DRAUGHTSMANSHIP COMPETITION

The winning entries in the annual Craftsmanship a Draughtsmanship Competition were displayed in t entrance hall and the judges' report and prize list a printed below.

As a possible thought for the Exhibition Committe would it be feasible to have a University and Technic College Section in the Craftsmanship competition? Un versity craftsmen can hardly compete on equal terms wi e in industry or Government establishments, since they y get detailed drawings to work to; but there is crafts- ship of a special kind in University workshops, par- arly in the direction of making satisfactory apparatus of vel type from rough drawings. It might be difficult to ate a competition for this kind of skill, but it could be rding.

e comments of the judges on the 1959 competition are llows:

es' Report

the classes for "scientific instruments and components" for "sections of instruments, functional scale models of ntific instruments and patterns" the workmanship was n of an extremely high standard. There were fewer s to be found with those competitors who did not enter prize list than has been the case in previous years and it regretted that there were not sufficient prizes to be awarded verybody.

e exhibits of "microwave components" in the senior e were very disappointing and it was not considered that award was justified. In the junior grade there was also n for improvement, particularly in detailed work and finish, and the standard was poor by comparison with the entries in the instrument making section.

Although there were only two entrants for the class for "optical components and systems," the optical quality of the work submitted was extremely high. The exhibits entered for the class for "blown-glass and silica ware" were also of a very high standard and considerable difficulty was found in deciding upon the eventual prize winners.

It was regretted that there were no entries for the class for "items showing draughtsmanship combined with craftsmanship" which was felt to give considerable scope for younger people.

One general fault in the entries for the Silvanus P. Thomson prize (in which competitors are required to submit a piece of craftsmanship as well as their own working drawings of it) was that the lack of boldness in the shape of the work gave insufficient contrast with the dimension lines. It is hoped to see more extensive use made of datum lines dimensioning components on drawings. The "models" were of an extremely high standard and it was again a difficult task to decide upon the prizewinner. It was very gratifying to see the increased number of entries in this difficult class and it is hoped that the improvement will be maintained in future years.

Craftsmanship and Draughtsmanship Competition

PRIZE LIST

Scientific instruments and components (Junior grade)

prize: B. W. Burrows (Cambridge Instrument Co. Ltd.). ompton electrometer with spare system.

nd prize: R. Starr (Services Electronics Research Laboratory). rystal goniometer.

Scientific instruments and components (Senior grade)

prize: P. J. Humphries (L. Oertling Ltd.). Precision balance r use in micro chemical analysis. Adjusted by competitor to sensitivity of 0·02 mg per division.

t prize: J. P. Phillips (Marconi's Wireless Telegraph Co. Ltd.). oystick resolver. A device to resolve an angle into components right angles for the control of a servomechanism rotating an rial to a given bearing.

ond prize: J. C. Matthams (Marconi's Wireless Telegraph Co. td.). L.C. unit. A variable industance-capacitor unit. Cover- ng frequency range from 400–500 kc/s with high stability over large temperature range.

it prize: E. J. Foster (Mullard Radio Valve Co. Ltd.). Elec- onic circuit designed to test and reject valve assemblies xhibiting short circuits, disconnected electrodes, and low esistance paths.

Microwave components (Junior grade)

st prize: J. J. Danbury (Services Electronics Research Labora- ory). Precision phase shifter X-band. A high-power waveguide omponent whose electrical length can be effectively varied by djustment of a double internal plunger.

nourable mention: R. J. Tucker (Hilger and Watts Ltd.). rototype Q-band calibrated variable attenuator, movable vane ype.

Optical components and systems

st prize: T. C. Dines (Hilger and Watts Ltd.). Quartz cornu rism for infra-red spectrophotometer.

ond prize: F. C. Turvell (Hilger and Watts Ltd.). Constant eviation prism in light flint glass for gauge interferometer.

rd prize: M. H. Williams (Research Laboratories of the General lectric Co. Ltd.). Three-stage mercury diffusion pump.

Blown-glass and silica ware (blown-glass)

First prize: A. H. Moore (Mullard Research Laboratories). Multi-spiral and ball condenser.

Second prize: D. W. Lanman (British Thomson-Houston Co. Ltd.). Three-stage mercury diffusion pump.

Honourable mention: M. J. Flynn ("Shell" Research Ltd.). Molecular weight apparatus. F. A. Daysh (General Electric Co. Ltd.). Two-stage mercury diffusion pump.

Blown-glass and silica ware (silica ware)

First prize: G. Gourley (The Thermal Syndicate Ltd.). Two-stage mercury condensation pump SK No. S.862.

Second prize: D. W. Lanman (British Thomson-Houston Co. Ltd.). Double surface silica reflux condenser.

Third prize: B. Conway (The Thermal Syndicate Ltd.). Allihn condenser SK No. T/T6/478.

Honourable mention: W. Money (The Thermal Syndicate Ltd.). Mercury fore pump SK No. S.869.

Instructional items, sections of instruments, functional scale models of scientific interest and patterns

First prize: A. W. Webster (Standard Telephones and Cables Ltd.). Fly press with blank and piercing tool (main frame fabricated, not cast).

Second prize: D. G. Irving (Standard Telephones and Cables Ltd.). Shore scleroscope, or hardness tester.

Third prize: F. W. Young (Standard Telephones and Cables Ltd.). Paper tearing tester (for resting the tearing resistance of cable insulating paper), and guillotine for cutting sample test pieces.

Silvanus P. Thomson Prize

J. P. Phillips (Marconi's Wireless Telegraph Co. Ltd.). Joy stick resolver. A device to resolve an angle into components at right angles for the control of a servo-mechanism.

ORIGINAL CONTRIBUTIONS

Quick-acting chemical balance

By B. O. Smith, M.Sc., A.Inst.P., and J. W. Stevens, Physics Department, British Iron and Steel Research Association, London

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The balance described is particularly well suited for use in an analytical laboratory in which repetitive weighings are made to an accuracy of one part in 5000. It is characterized by rapidity of operation, and robustness of suspension. Its regular use should enble substantial savings in time and labour to be made. The beam is balanced by an electronic servo system with a fast response speed and excellent long-term reliability.

Although the analytical balance has undergone many improvements in the last 100 years or so, these have, in essence, been improvements in detailed design and not in the basic principle of operation. As it stands today, the balance is capable of performing weighing operations to a high degree of accuracy. It does, however, suffer from two basic limitations which, in certain kinds of use, become important. These limitations are that the knife-edges and planes used as beam and pan pivots have a limited life, which can be considerably shortened by incorrect handling, and that the time taken to perform a weighing operation is appreciable. When the balance is used to make, say, 20 weighing operations per day in a laboratory, neither of these limitations is important. In certain industrial laboratories, however, a balance may have to make many hundreds, or even thousands, of weighings a day. Under these conditions, the combination of weighing time and limited knife-edge life reduces both the daily capacity and useful life of the balance.

A balance has therefore been developed in which the emphasis is placed on high speed of operation and long-term reliability. The load specification of 5 g maximum weighed to an accuracy of 1 mg is lower than with many conventional balances, but it is more than adequate for many kinds of repetitive weighing.

GENERAL DESIGN PRINCIPLES

From the beginning, it was appreciated that the problem of limited knife-edge life could be approached in two ways. Either conventional knife-edges and planes could be retained with the emphasis on a search for new and more reliable materials, or alternative types of restraint-free pivots suitable for a balance beam could be tried. The cross-spring hinge was finally adopted as the most promising line of approach.

To speed up weighing operations, it is necessary to remove the need for arresting the beam when any changes of loading occur, and to give the beam assembly a short period of oscillation with near-critical damping. It was thought that the cross-spring hinge would meet this first requirement. For the second, it was considered desirable that the beam should not be under gravity control, but should form part of a servo system. In this way, the natural frequency of oscillation of the beam is not dictated by its own mechanical characteristics, but depends very largely on the electrical characteristics of the servo system controlling it. These are capable of wide adjustment quite easily. The beam, therefore, was freely suspended to pivot on an axis through its centre of gravity, and the whole of the restoring force necessary to oppose an applied load was generated by means of a servo system. In effect, the system was designed a simple force-balance servo.

A schematic diagram of the complete instrument is sho in Fig. 1. A beam and two-pan assembly of conventio appearance is used, the main beam pivot being a cross-spri hinge. Displacement of the beam under the action of a lo in one pan is measured by a suitable displacement transduc which generates the input signal to an electronic amplifi The output from the amplifier is in the form of a dir current, the polarity of which is directly related to the directi of the beam displacement. This current is used to apply restoring force to the beam by a moving coil and permane magnet assembly. Because the force generated is direct proportional to this current, the steady current existing wh the beam reaches equilibrium may be taken as a measure the applied load. It is convenient to consider the desig features of the instrument in three parts; the mechanic design features of the balance itself, the circuit of th electronic amplifier, and the display unit.

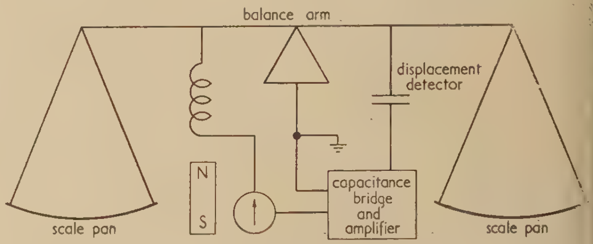

Fig. 1. Schematic diagram of balance

THE BALANCE

As can be seen from the photograph in Fig. 2, the balan unit itself is of fairly conventional appearance. The bea which is 20 cm long, is fabricated from two light-allo girders, at each end of which are small counterweights screw adjustments to enable the centre of gravity of th beam assembly, to be located accurately at the point rotation. On the prototype instrument, no provision is ma for adjusting the position of the pan supports to give precise equal lengths of the two balance arms. It has been foun in practice that the ratio of arm lengths differs from unit by about 0·02%. The beam is suspended from a centra massive pillar and cross arm by means of a double cros spring hinge assembly. An upper U-shaped member anchored rigidly to the cross bar while the lower member

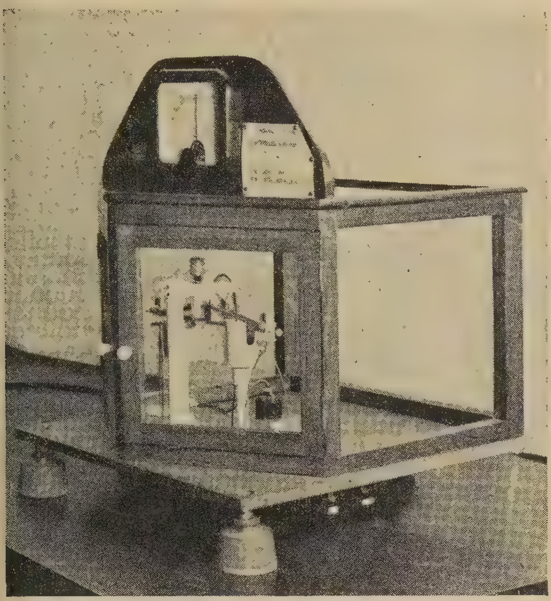

Fig. 2. Balance unit

ched to the balance beam. The cross-spring hinges nselves consist of four phosphor-bronze strips, the free th being 0·1 in., the width 0·1 in. and the thickness)2 in. The stiffness of this spring assembly is such that ill support easily a load of 5 g in each pan in addition ne weight of the pan and beam assembly, and the restraint cised by the spring in normal deflexions of the beam is valent to a load of less than 0·25 mg in either pan. s, small changes in the stiffness of these springs do not rfere with the accuracy of the instrument. Although it is nded that the pan pivots should be of similar construction the main beam pivots, the prototype was nevertheless plified in this respect, and the pivots actually used for the consist simply of a bifilar nylon-thread suspension. This been found remarkably robust and sufficiently accurate lemonstrate the capabilities of the prototype instrument.

he displacement detector is mounted on the right-hand of the beam, and consists of a moving-plate capacitor em. The upper plate, 1 in. in diameter, which is trically earthed, is attached to the underside of the ance beam, while the lower plate, which is electrically , is rigidly mounted on a supporting pillar fixed to the e board of the instrument. The normal separation of se two plates, with the beam in an equilibrium position, bout 0·012 in. and the movement of the beam in normal ration corresponds to an increased or reduced separation these two plates of about 0·004 in. The whole of the placement detector is housed in a massive brass cylinder ch serves the dual purpose of protecting the displacement ector against mechanical damage and providing adequate trical screening.

similar mechanical construction has been used for the oring-coil assembly on the opposite side of the beam. A ill pot-type permanent magnet on a supporting pillar is dly fixed to the base board. The restoring coil itself sists of 250 turns of 45 s.w.g. enamelled copper wire ind on a self-supporting former. This former is then nented to the underside of the beam in the appropriate ition. To cut down the need for twin pigtail connexions his restoring coil, the cross-spring hinge itself is used for one electrical connexion. The second connexion to the coil is made by means of a light-gauge wire pigtail. The balance pans themselves are of conventional construction hanging from a single-hook pivot on a cross bar attached to the bifilar suspension mentioned previously.

Some trouble was experienced with lateral oscillations of the pans after careless loading. With a conventional balance, this problem does not arise, because the pans are arrested during any load changes but, with a live-beam system, incorrect loading can cause serious lateral oscillations of the pans. The design of a suitable damping system presented certain difficulties because, if the pans are loaded non-centrally, they will not hang vertically. The system finally adopted was to attach to the underside of each pan a small ball about $\frac{1}{8}$ in. diameter on a $\frac{1}{2}$ in. length of spring wire, hanging vertically downwards. This ball can engage in a tapered cup, the minimum diameter of which is equal to the ball diameter. These cups are capable of retraction by means of a side lever. If a pan is swinging, the cups are raised to engage the ball in their minimum diameter. When they are released again, the ball slides gently along the taper and allows the pan to take up a non-vertical position but with its lateral oscillation in either direction damped out.

All components of the balance unit are mounted on a square base made from $\frac{1}{2}$ in. thick Tufnol, which is supported on three resilient mounts fitted with levelling screws. The whole unit is enclosed in a conventional wood and glass case. It will be seen from Fig. 2 that the case and base board are considerably larger than is needed for the present design of balance unit. This has arisen because the base board and case were constructed to house an earlier prototype.

THE ELECTRONIC AMPLIFIER

The electronic amplifier is, for convenience, housed in two separate units. The first, the detector amplifier, is a standard proximity meter (type number PM2, by Fielden Electronics Ltd.), of which a schematic diagram is shown in Fig. 3.

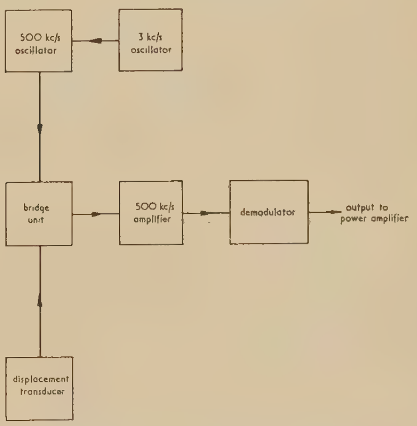

Fig. 3. Block diagram of detector amplifier

The moving-plate capacitor on the balance beam forms one arm of a 500 kc/s bridge, the energizing voltage being modulated at 3 kc/s. This bridge is adjusted to give zero output with the moving-plate capacitor at maximum capacitance, i.e. at minimum separation. For any increased separation, i.e. upward movement of this half of the balance beam, an output voltage is generated from the bridge which is amplified and demodulated, giving a 3 kc/s signal at the output terminals of the proximity meter.

Without drastic modification of this unit, it is not possible to obtain an output balanced about zero with a phase change on passing through zero. The power-amplifier unit which must effectively give positive or negative outputs was therefore designed to accept inputs ranging from zero to maximum. It is shown in Fig. 4.

a restoring current of about 20 mA. Provision is made the shunt-resistor network for potentiometers to ensure t the balance remains accurate on calibration. The disp meter itself is mounted at the top of the balance case, a the resistor network and adjusting potentiometers mounted below the base board of the balance unit.

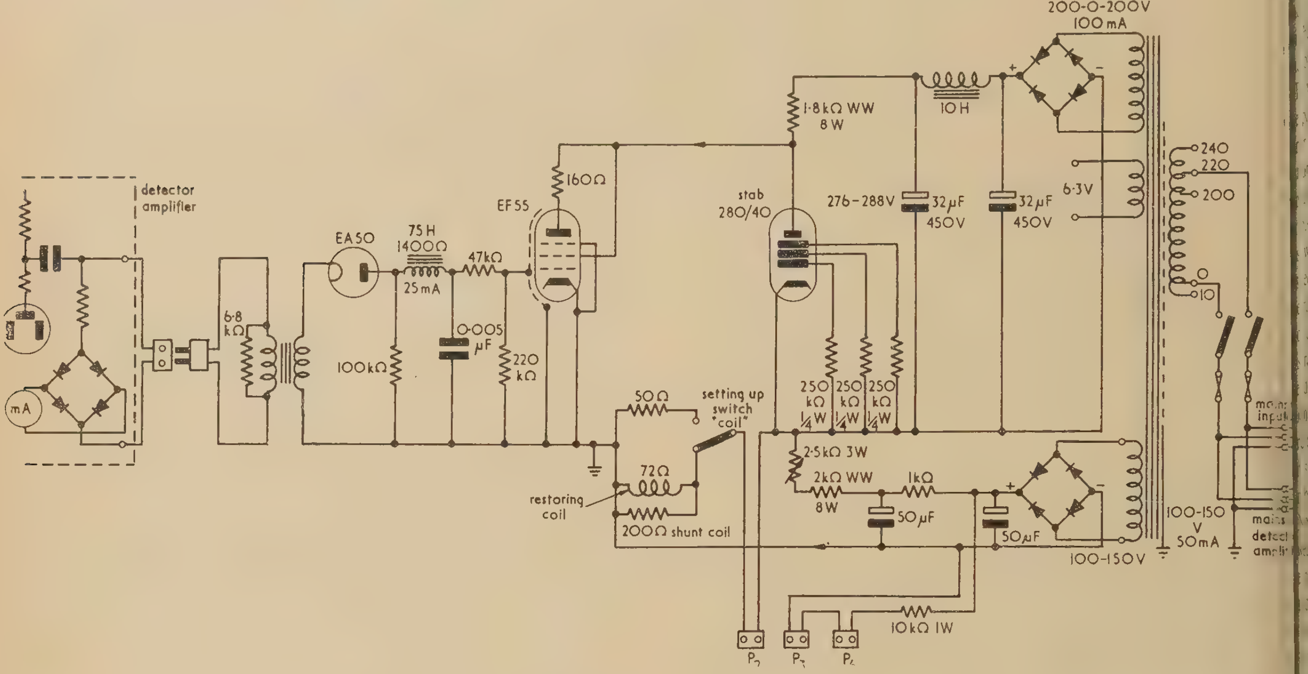
detector
amplifier
mA
6·8 kΩ
EA50
75 H
1400Ω
25 mA
47kΩ
100kΩ
0·005 μF
220 kΩ
EF55
160Ω
stab 280/40
1·8 kΩ WW 8 W
10 H
200-0-200V
100 mA
276–288V
32 μF 450V
32 μF 450V
6·3V
240
220
200
0
10
250 kΩ ¼W
250 kΩ ¼W
250 kΩ ¼W
50 Ω
setting up switch "coil"
72Ω
restoring coil
200Ω shunt coil
2·5kΩ 3W
2kΩ WW 8W
1kΩ
50 μF
50 μF
100-150 V 50mA
100–150V
10kΩ 1W
P₇
P₇
P₄

Fig. 4. Power amplifier

The input 3 kc/s signal is transformer-coupled to a rectifier and filter stage, and the resulting voltage applied to a d.c. amplifier stage consisting of an EF55. The cathode of the EF55 is earthed and connected to the negative h.t. supply through the restoring coil of the balance. The h.t. supply is therefore "floating" a few volts from earth potential. This arrangement was necessary to meet the twin requirements of keeping one side of the input and one side of the output at earth potential. The EF55 is supplied from a 280 V stabilized supply and at maximum input is passing 44 mA.

To give the required balanced output current through the restoring coil, a "backing off" current of 24 mA is provided by a separate 100 V h.t. supply which does not introduce shunt effects on the main circuit. It has not proved necessary for this circuit to be stabilized. Provision is also made for the restoring coil to be switched out of circuit and a 50 Ω dummy load introduced, to assist in setting up the equipment.

THE DISPLAY UNIT

Weighings are displayed on a high-grade moving-coil microammeter graduated to read 100–0–100 which has a centre-reading 400–0–400 μA movement. As shown in Fig. 5, a shunt-resistor network enables two scales to be provided, either of which may be selected by means of a foot switch. The fine range gives weighings up to 100 mg with an accuracy of 1%. A reading of 100 mg represents a current of approximately 400 μA passing through the restoring coil in the equilibrium condition. The coarse range permits weighings up to 5 g, corresponding at equilibrium to

important feature of the resistor network is that it represen approximately the same series impedance in the outp circuit on either of the two ranges. This was found to most important, because change from one range to anoth introduced a transient disturbance into the system if a resistance change occurred.

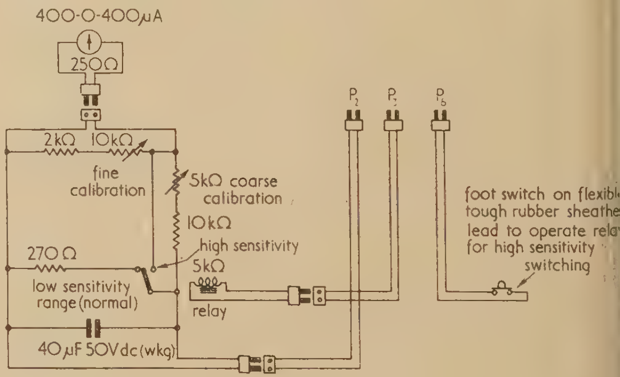
400-0-400μA
250Ω
2kΩ
10kΩ
fine calibration
5kΩ coarse calibration
10kΩ
high sensitivity
5kΩ
270 Ω
low sensitivity range (normal)
relay
40μF 50V dc (wkg)
P₂
P₃
P₆
foot switch on flexibl
tough rubber sheathe
lead to operate rela
for high sensitivity
switching

Fig. 5. Display unit

METHOD OF OPERATION

Weighing operations normally fall into one of two ca gories. These are (i) the precise weighing of a particula object and (ii) the weighing out of a pre-determined quantit of a powder, granular or liquid sample, usually into prepared container.

To weigh a particular object, the object is placed in on

of the balance on the coarse range, and its weight is
ediately read to an accuracy of ±50 mg. Counter-
hts are now added to the other pan to the nearest 100 mg.
important feature of this balance is that, for this type of
hing, only one weight-loading operation is performed,
pared with a number of trial-and-error weighings on a
entional balance in this range. When the balance
s approximately zero on the coarse range, it can be
ched to the fine range, when the residual weight can be
off and added to the weight previously loaded.

weigh out a powder sample, the container is placed in
pan and the counterweight, equal in weight to the con-
r plus load, is placed in the other pan. Then with the
ument on the coarse range, the sample is added to the
ainer until the meter reads approximately zero. Since
his range the meter can be read to an accuracy of ±50 mg,
will mean that the load is now within 50 mg of the
red weight. The balance can then be switched to the
range which will display 100 mg for full-scale deflexion,
further additions can be made to give a zero reading on
range. The weighed-out sample will than have reached
desired value. The advantage shown by this type of
nce for this class of weighing operation is that, at any
during the operation, the residual error in the weighed-
sample is continually displayed, and that all additions
be made with the beam swinging.

o attempt has been made in the prototype to incorporate
eight-loading attachment of the kind commonly fitted to
better-quality analytical balances. These are regarded as
dard pieces of mechanism and could obviously be added
his type of balance. Nevertheless, with the use of a box
ose weights of the usual variety, it has been found possible
veigh objects regularly in a time of between 15 and 20
nds. This represents a saving of time of at least 75%
pared with a normal analytical balance.

TRIALS OF THE INSTRUMENT

During the last two years, the instrument has undergone a number of trials to establish the stability of calibration and the mechanical reliability of the system. During this period, no breakdowns have occurred and it seems that the pivot of the cross-spring hinge will last almost indefinitely unless grossly mishandled. No trouble has been experienced with the electronic units and the calibration of the balance has remained remarkably stable. It is found in practice that a weekly check of calibration accuracy is quite sufficient, although it is rare for adjustment to be needed with this frequency of checking. No adjustment of gain setting or zero-balance of the detector was found necessary during periods of several weeks. Results so far obtained confirm the opinion that this balance is capable of approximately 3 to 4 times as many weighing operations per hour as a balance of conventional type.

CONCLUSIONS

This balance is particularly well suited for use in an analytical laboratory in which large numbers of repetitive weighings have to be carried out to an accuracy of about one part in 5000. It is characterized by rapidity of operation and robustness of suspension. Its regular use should enable substantial savings in time and labour to be made.

ACKNOWLEDGEMENTS

The authors are indebted to the management and staff of Rylands Bros. Ltd., for assistance in carrying out the trials of the instrument. They are also indebted to Fielden Electronics Ltd., for permission to quote details of the proximity meter, type number PM2.

Geiger counter hodoscope with automatic testing

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A multi-channel Geiger counter hodoscope is described which records automatically on punch cards, uses a simple but effective quenching circuit and contains a testing circuit. An automatic hourly test is applied to all channels, providing a random sample of their behaviour and enabling speedy detection of faults either in the counters themselves or the associated recording circuits.

he operation of a multi-channel Geiger counter hodoscope
essential to ensure the continued correct operation of all
nnels and to be able to locate and rectify faults expedi-
isly. Experience of one of us with a previous hodoscope(1)
wed that the frequent testing of all channels was essential
that the time required to check its eighty-seven channels
vidually was considerable.

s a possible 800 channels were required for the hodoscope
cribed here (200 are at present in use), provision was made
rapid automatic hourly testing of all channels. When
g a large number of Geiger counters in an experiment
ch might run for some years it is desirable to prolong
r life by the use of quenching circuits. This of course
eases failure rate in the electronic circuitry, but with the
efficient system of fault detection described here the overall result is:

(i) early detection of faults;

(ii) a reduction of time spent in checking the apparatus and locating faults;

(iii) an increase in the total useful operating time.

GENERAL OPERATION

A block diagram of the apparatus is shown in Fig. 1. The quenching circuit Q associated with each Geiger counter provides, in addition to a quenching pulse, a pulse to the appropriate storage circuit GS. The latter is unaffected unless gated by a master pulse. The quenching and storage circuits are arranged twelve to a chassis to correspond to the twelve rows on the standard punch card on which the results are recorded automatically. The quenching circuits also provide a pulse to an addition circuit *A* which provides an output pulse approximately proportional to the number of counters which fire. The output from the addition circuit is amplified and fed to the coincidence circuit *CC*. Provision is made for switching each individual input to the coincidence circuit so that the multiplicity of coincidences can be readily varied as desired. This is also very useful for checking purposes. The output from the coincidence circuit triggers a circuit *M* which provides a master pulse of 1·5 μs duration. This master pulse circuit produces:

(i) a gating pulse to all storage circuits;

(ii) a trigger pulse for the start circuit *S* which initiates and controls the stepping from column to column of the punch machine *P* and uniselectors *U*;

(iii) a pulse which paralyses the coincidence circuit so as to prevent further master pulses during recording.

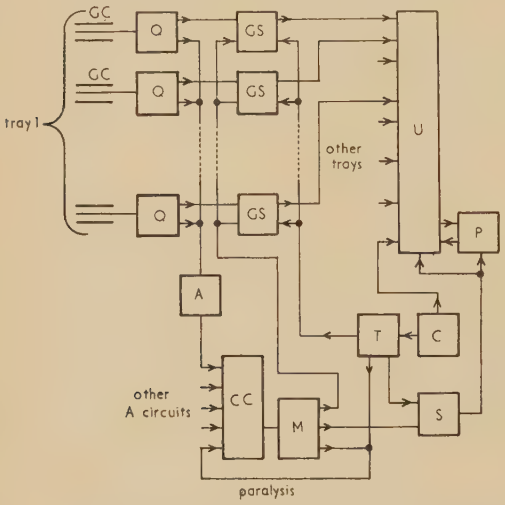

Fig. 1. Block diagram of Geiger counter hodoscope

A, addition circuit; *C*, clock; *CC*, coincidence circuit; *GC*, Geiger counter; *GS*, gate and storage circuit; *M*, master pulse circuit; *P*, punch machine; *Q*, quench circuit; *S*, start circuit; *T*, test circuit; *U*, uniselectors.

When a coincidence occurs, a positive d.c. voltage appears at those storage circuits which get an input from the quenching circuit in coincidence with a master pulse. This voltage is fed *via* the uniselectors to the punch machine *P* and causes a hole to be punched at the appropriate position on the card.

A clock *C* is used to switch on automatically every hour a test sequence which can also be initiated at any time by means of a manual switch. If recording of an event is in progress, the test is inhibited until this recording is complete. The test circuit *T* also paralyses the coincidence circuit during performance of a test. A circuit associated with the clock is also used to punch the date and hour of each event on the cards.

QUENCHING AND STORAGE CIRCUIT

The Geiger counters are of the external cathode type and, in order that their effective length may be accurately known, they are designed in accordance with the principles set out by Grouse and Rathgeber.(2)

The quenching circuit should provide a negative p which as rapidly as possible reduces the counter volt below the starting voltage (in the authors' case a puls 150 V was required). In cosmic-ray work where the coun rate is essentially the background rate and loss of cou due to counter dead time is negligible, it is also a dist advantage for the quenching pulse to be long enough prevent double pulses.

Each batch of counters is tested on the filling system the pressure adjusted to give a uniform starting voltage 1000 V. A tolerance of ±20 V is allowed, so that, fo reasonable margin of safety, the quenching pulse should about 200 V. A pulse width of 350 μs was chosen. Thi long enough to prevent double pulses in the largest coun used and short enough not to introduce significant cou dead time. In experiments where a short counter dead ti is important the duration of the quenching pulse can reduced to the order of 10 μs. The pulses to the addit circuit and storage circuit (Fig. 2) should, like the mas pulse, be no more than a few microseconds in order to ren negligible the rate of accidental recording due to ch overlap with a master pulse.

Valve V_1 is a univibrator quenching circuit. The f anode is normally at +300 V and provides a portion of Geiger high-tension. In this respect it is similar to a circ described by Elliot.(3) On the occurrence of a Geiger pul V_1 acts as a fast plate-coupled univibrator with coupling the cathode follower V_2 to drive the grid of V_{1A} into grid-current region and provide a fast-rising quenching pul The coupling between V_1 and V_2 has a time constant o few microseconds and provides a large pulse of effect

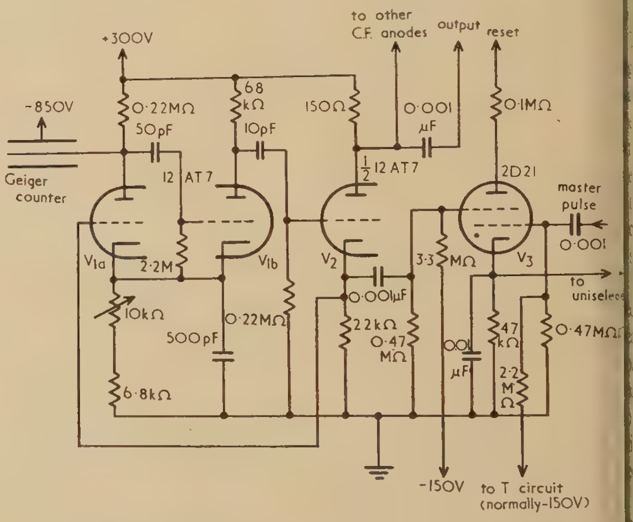

Fig. 2. Quenching, storage and addition circuit

duration of 2 μs at the cathode to drive the second grid storage thyratron V_3. The cathode follower also serves isolate V_3 from the quenching circuit. The cathode capaci of V_1 is large enough to by-pass the initial pulse, and t quenching pulse rises to 250 V with a rise time of 0·3 (The Geiger counter is quenched in 0·2 μs.) After the fi few microseconds the quenching univibrator becomes catho coupled, the by-pass capacitor being small enough to ha no further effect, and the pulse height drops to 200 V (fo cathode bias of 28 V, but the bias is variable by means of t potentiometer as a sensitivity control), remaining perfect flat for the remainder of the pulse. If the by-pass capaci o large, the initial fast pulse decays before the long, slow e takes over.

small anode resistor common to all the cathode followers es a simple and effective addition circuit. This arrange- t is quite versatile and can be used to vary the triggering uirements of the whole apparatus. It may, with a suitable riminator, be used to require a greater number of counters re for an output pulse. It is also possible to exclude any ger counters from the triggering arrangement but still rd whether they fire by connecting the relevant cathode ower anodes direct to the +300 V line. The cathode ower anode lines of several chassis may be commoned in er to provide a single output from a tray of more than ve counters.

he output pulse is amplified, shaped and fed to a nanium diode coincidence circuit. The discriminator ibined with a trigger circuit delivers an 80 V pulse which s to 50 V in less than 0·1 μs. The use of two double- nanium diode circuits(4) separates the functions of dis- iination and of inhibition of self-triggering, which latter articularly important in a positive feedback loop of high plification. It was found that the particular design used le the output pulse independent of discriminator setting of pulse size and shape.

n order to produce the rectangular master pulses of 1·5 μs ation, the coincidence circuit drives, through a cathode ower, a series of thyratrons. These each have their anode l by-passed by an open-ended 70 Ω line which reflects negative pulse produced when the thyratron fires and so it off. This line is matched by the impedance of the ratron in series with the cathode load, consisting of two Ω coaxial lines in parallel, which feed the master pulses he respective counter trays and also to the start circuit.

he storage thyratrons fire when a pulse from the quench- circuit appears at the second grid in coincidence with a ster pulse at the first grid. The cathodes (at 85 V when thyratron fires) are connected to the recording uniselectors. the end of recording, the thyratrons are quenched by ans of a relay contact which momentarily interrupts the supply. The coincidence circuit is paralysed during ording to prevent any further master pulses by applying iitable bias to a diode in the coincidence circuit.

he recording time is determined by the speed of the ording equipment only, since the storage thyratrons are dy for recording a few microseconds after an event. As rate of recording at present is very low, no effort was de to obtain high-speed recording. It appears possible reduce the present recording time of 15 s to a few seconds h high-speed punching equipment and to a fraction of a ond with magnetic tape storage.

The circuit is quite economical in h.t. power, each channel wing 3 mA when quiescent and a further 2 mA when V_3 s. Altogether quite an efficient circuit has been devised h simple design and relatively few components, this being important consideration for a large number of channels.

AUTOMATIC TESTING

A test is normally initiated on the hour by means of the ck. Provision is made for two or three tests in succession lesired, but in practice one is found to be sufficient. The thod of testing is to switch the first grid of all the V_3 to oositive voltage for a predetermined time by means of a ay contact. In this way a random sample of Geiger inter firings is obtained.

Geiger counter circuits, especially those containing quenching circuits, can fail in one of two ways:

(i) the counting rate falls or ceases altogether;
(ii) the counting rate rises, perhaps to a continuous oscillation at a frequency governed by the dead time of the counter or quenching circuit.

Two tests are required, one of sufficient duration t_l for approximately 90% of the counters to fire (long test) and one sufficient duration t_s for approximately 10% to fire (short test) in order to detect faults of type (i) and (ii) respectively.

The test circuit first provides a long test and then operates the start circuit. When the long test is recorded, this procedure is repeated for the short test. The paralysis circuit is released two minutes after the initiation of the test so that the time lost in testing is accurately known.

The probability of a pulse within a given time interval t is simply $1 - \exp(-nt)$ where n is the average counting rate. The duration of the long and short tests t_l and t_s are given respectively by

$$t_l = -(1/n)\ln 0{\cdot}1$$

$$t_s = -(1/n)\ln 0{\cdot}9$$

The test times t_l and t_s are determined solely by the Geiger counter rates n, and different test times must be provided for each size of counter used.

This form of testing has been found to be invaluable. It allows very speedy location of faulty channels. Having discovered a faulty channel, the test procedure is useful in locating the faulty component, e.g. if a valve is suspect it can be replaced or switched with an adjacent channel and a manual test immediately applied.

It is usual, when first switching on, to make a number of manual tests. By far the most common type of fault is a complete failure of a component. Three tests are usually sufficient to indicate this type of fault, as the probability of either three hits in successive short tests or three misses in successive long tests is only 0·1%. Similarly, when operating it is usually sufficient to examine the last three hourly tests. The examination can be performed rapidly by holding the three long test cards against a light background and the short test cards against a dark background. If a fault is indicated, the hourly test cards can be used to determine the approximate time of failure and subsequent events can either be rejected or allowance can be made for the fault. It is desirable to examine at regular intervals a larger series of test cards in order to detect any significant drift in counting rate short of complete failure.

ACKNOWLEDGEMENTS

We would like to thank Prof. H. Messel and the Nuclear Research Foundation for their support for this work. One of us (H. S. M.) would like to thank C.S.I.R.O. for the grant of a studentship during the development of the equipment described here.

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Monitored Geiger counter X-ray diffractometer with automatic recording

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The equipment produces automatically a compact photographic record of a step-scan of a powder diffraction pattern in steps of 0·02° (2θ). It is arranged that movement over the background region between lines is rapid, so that only the line profile and the immediate background on either side are recorded in detail. The specialized electronic circuits and the relay-operated automatic sequence control circuits are described, together with a special automatic camera provided with various safety devices to protect the record. Facilities for other scanning procedures are also provided.

The instrument to be described has been designed and constructed in order to obtain with high accuracy, and with the minimum of labour and of loss of time, records of the intensity of the X-ray beam diffracted by a substance in powder form mounted upon a diffractometer in the usual manner. The information embodied in such records may be used directly to plot "line profiles" of the diffraction lines, and these in turn may be used in various ways.(1) The particular application for which the instrument is designed is the listing of accurate line positions and intensities for the A.S.T.M. Powder Data File. For this work the diffractometer has the advantages over photographic methods of increased speed, high resolution and better intensity measurement. In addition, if the positions of the centres of gravity of the lines, rather than the peak positions, are obtained from the recorded figures and listed in the File, aberrations arising from the geometry of the particular instrument used in the work may be eliminated beforehand.(2) Again, the peak intensity of a line is more sensitive to instrumental shortcomings than is the integrated intensity; the present instrument can give the latter quantity directly for lines which are clearly resolved.

The instruments hitherto available for recording diffraction patterns use either continuous scanning with chart recording,(3) or some form of "step-scanning." To obtain the maximum accuracy in the first of these requires a slow scanning speed, and correction of the recorded pattern for distortion introduced by the characteristics of the ratemeter which is associated with the X-ray detector.(4, 5) A step-scan which uses the "fixed-count" method is time-consuming, requires a highly-stabilized X-ray generator and is more precise than is necessary at low counting-rates. In either case, unless scintillation or proportional counters(6, 7) are used (and this necessitates additional electronic equipment), the record needs further correction for the finite "dead-time" of the Geiger counter normally used for detection.

A monitored arrangement can minimize the difficulties associated with step-scanning, and also permits the use of an electronic circuit(8) which eliminates the need for any further correction for "dead-time" of the record actually obtained. In the instrument described here such an arrangement is used, together with a photographic process for recording which is faster than the earlier mechanical methods,(9–12) and which gives records which are much less bulky. A considerable improvement on earlier equipment(13) has been achieved by making the entire action of the instrument fully automatic.

FACILITIES OF THE PRESENT INSTRUMENT

A brief outline of the main features of the instrument h already been published.(14) The diffraction pattern scanned in steps of 0·02° (2θ) with a slightly modifi Norelco goniometer, using a Geiger counter as detector. monitor counter, together with the circuit mentioned above, ensures that the number of counts recorded in each positio needs no further correction. Since the dead-time of th Geiger counter makes the minimum time between pulses the order of 300 μs, Dekatron decade scalers (by Ericsso Telephones Ltd.) may be used for direct indication of bo the monitor counts and those from the "specimen" detecto on the diffractometer. The readings of the scaler dealin with the latter, together with those of an angular positio indicator, are conveniently and compactly recorded microfilm.

The automatic step-scanning sequence is basically follows: the "specimen" and "monitor" scalers are starte simultaneously, and the incoming quanta are registered both channels until the required monitor total has bee accumulated. The receipt of the last monitor count caus both scalers to stop counting; the total displayed by th specimen scaler, and the reading of the angular positio indicator situated beside it, are then photographed by a automatic camera. The control circuits then automaticall move the film on, reset the scalers to zero, and move on th diffractometer arm one step. The scalers are then restarte and the sequence continues until it is stopped manually, b the action of the limit stops on the diffractometer or b exhaustion of the film in the camera.

However, the useful information in a diffraction pattern contained in the positions and intensities of the "lines," an not in the stretches of "background" between them. I order to cover the whole diffraction region in a practicab time, and yet to maintain adequate accuracy in the individua readings, the basic action is elaborated so that only th "lines" and a little of the background on either side of the are recorded. The rest of the diffraction region is covere rapidly without recording. An additional scaler can no record separately the sum of the individual readings take across a line, from which its integrated intensity may b obtained.

The modified operating sequence is as follows: aft establishing (by means considered later) a "reference level for the background counting rate, it can be arranged that relay operates when the counting rate in any fixed positio of the goniometer arm exceeds this level. The reference leve can be set at a fixed counting rate for the whole pattern c can be arranged to set itself automatically at a fixed heigh ve the actual background over the region where the kground decreases monotonically. Unless the relay has ated, the arm is moved through steps ten times as large he fundamental 0·02° interval, and is kept stationary in position only long enough for the counting-rate meter ttain a steady state. If the counting rate is not then high ıgh to operate the relay, a further large step is taken, in this way the background is rapidly scanned until the nting rate exceeds the reference level. Then the relay ates, and the counter arm is moved backwards through large steps so that it is again in the background before line; the basic step-scanning sequence with monitored rding is then started, and continues for twenty small s, i.e. two large steps. The counting rate now exceeds reference level, and the scan continues through the line l the counting rate falls below the reference level. The y then releases, but the basic sequence continues for her ten small steps. The counter is now in the backund beyond the line, and at the end of the sequence the grated intensity is recorded; larger steps are now taken l the next line is reached. If a doublet or a pair of ely-spaced lines is being recorded, and the reference level ot reached again before the second line occurs, the blet is scanned as a single line and its integrated intensity corded at the end of the second line. The same action s place if the reference level is reached at the end of the line, but is exceeded again because of the proximity of second line at the position where the integrated intensity he first would otherwise have been recorded. If the nd line is in such a position that the reference level is eded one large step after the integrated intensity of the line has been recorded, the counter arm is moved back ugh only one large step instead of two, to avoid recording preceding region twice.

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many complex patterns the lines over a large part of record are so close together that recording as individual upon a given background is not possible. In such cases grated intensities and centres of gravity are of such ted accuracy that peak positions and intensities are of e value. To facilitate the recording of only the peaks of main lines of the pattern, a circuit is built into the aratus so that the reference level can be set to a value siderably above the background and a scan made. This rried out in a manner similar to the one described above recording lines only, but reversing only ten steps when a is encountered and moving off in the large steps ıediately the reference level is reached on the other side he peak. In such a scan, therefore, the portions of the occuring just before and just after the reference level is hed are not recorded, as they are in the previous proıre where the "tails" are also required.

lthough the instrument has been designed mainly for -scanning, the usual facilities for chart recording with tinuous scanning have also been incorporated. The ipment can, in fact, operate in five different ways (*A*, *B*, *D*, *E*); these are *A*, step-scan with background disination; *B*, basic step-scan; *C*, continuous scan with t recording; *D*, manual step-scan; *E*, step-scan peaks .

ach may be initiated by a push-button on the control el, and the operation of either a further push-button or of the adjustable limit switches on the goniometer or ustion of the film in the camera stops the scan. Before an be started, the gears on the diffractometer have to be ged. In *D*, one step is taken and a count is made each the button is pressed, and the scaler and angular position indicator readings are recorded by hand instead of being photographed.

GENERAL LAYOUT

The block diagram (Fig. 1) shows the layout of the circuits, and Fig. 2 the complete equipment. The pulses from the monitor and specimen Geiger counters are fed to the dead-time correction circuit, and the negative-going output pulses

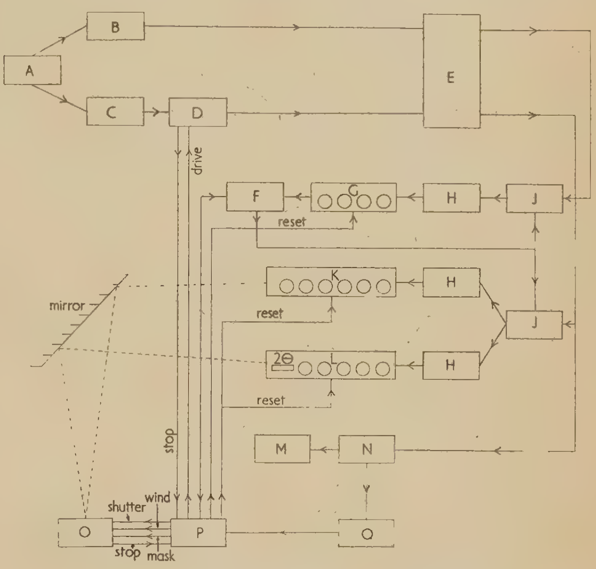

Fig. 1. Block diagram of the equipment

A, X-ray generator; *B*, monitor Geiger; *C*, specimen Geiger; *D*, diffractometer; *E*, dead-time correction circuit; *F*, scalers on/off; *G*, monitor scaler; *H*, shaper; *J*, phase inverter and gate; *K*, integrator scaler; *L*, specimen scaler; *M*, chart recorder; *N*, rate-meter; *O*, camera; *P*, sequence control; *Q*, set background.

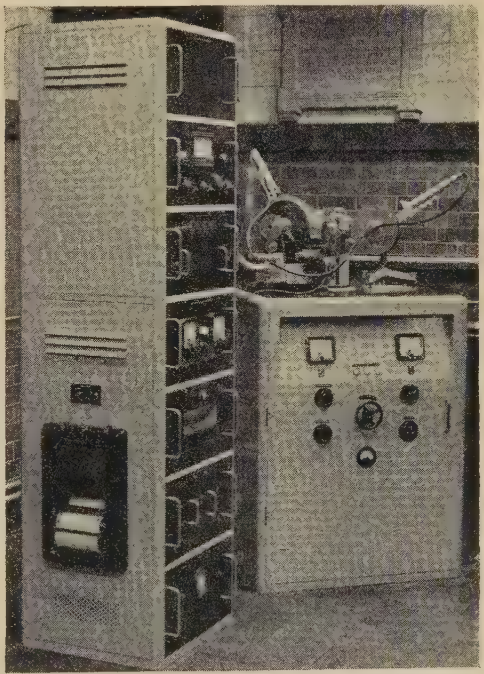

Fig. 2. General view of the complete instrument

in each channel are applied to phase-inverting stages to provide positive-going pulses for operating the Dekatron scalers. These stages are conveniently used for "gating" the input to each scaler. The monitor scaler can give an output pulse at either the 1000th or 10000th count, and this is fed to a thyratron circuit which performs the switching operations considered below. The specimen scaler and the integrating scaler are fed in parallel; either or both of these may be photographed at instants determined by the control unit. The specimen-channel signals from the dead-time correction circuit are also fed into a third channel for the counting-rate meter and the background-discrimination circuits and the chart recorder. The sequence control unit collects signals from different parts of the equipment and programmes its operation in accordance with the method of scanning selected by the push-buttons on the control panel. The circuits are rack-mounted, and the automatic camera is embodied in one of the lower panels; an optical path of appropriate length is obtained between its lens and the scalers by means to be discussed later.

The X-ray generator uses a four-window sealed-off Philips tube, mounted vertically, and is self-rectifying, operating from a half-wave supply. The control circuits and safety devices employed follow standard practice. The tube shield is bolted rigidly to a horizontal steel plate 32 × 32 × $\frac{3}{8}$ in. which forms the top of the generator cabinet, and the specimen and monitor goniometers are mounted upon this plate on opposite sides of the X-ray tube. Both goniometers are located in position by the conventional hole, slot and plane arrangement. In the case of the monitor, a Duralumin plate bolted to the steel plate carries the hole and slot, but for the specimen the steel plate forms the plane, and the hole and slot are carried on a key-shaped Duralumin plate which rests on the steel plate but is pivoted about the axis of the X-ray tube, so that the plane of symmetry of the beam path through the goniometer always contains this axis. This simplifies the lining-up procedure.

The monitor goniometer is arranged to have the same radius and take-off angle as the specimen goniometer. A powdered aluminium specimen is used, and there are Soller slits near the tube window to reduce stray radiation; a wide receiving slit avoids errors due to minor shifts of the position of the X-ray focus. The final adjustment of the slit position is checked photographically. Foils of aluminium or nickel may be placed in the path of the diffracted beam to adjust the time taken to complete the monitor count.

The specimen goniometer is a modified form of the Norelco high-angle instrument. The main modifications were made so that the step-scanning gears could be driven through a flexible cable from a motor in the main rack, and to permit the enclosure of this cable, together with control wiring and the coaxial cables for the two Geiger counters, in a protective flexible metal tube. The Geiger counters are connected to Plessey Mark IV sockets mounted on the goniometer, and special low-capacity cable (8 pF/ft) minimizes the effect of separating the counters from the quenching circuits by distances of some 3 ft. When continuous-scanning is required, the changing of the gears brings into use a synchronous motor mounted on the goniometer itself.

CIRCUIT DETAILS

Though some of the circuits depart very little from conventional practice, there are others which have either been modified or specially designed for this equipment. These are discussed in the sections below. (The numbering in the figures is that of the full set of diagrams for the instrume only a few of which are reproduced here.)

(a) *Geiger counter h.t. supplies*

A highly-stabilized commercial unit (by Isotope Devel ments Ltd.), variable in three ranges up to 3 kV, has b modified to provide two outputs, which may be control independently and measured on the same panel meter. chain of fixed resistors, with a variable potential divider the upper end, is placed across the first output to provide second; a changeover switch applies the meter circuit to eit output. The second output voltage may be varied from same value as the first to a value which, at 1500 V, is rat more than 100 V below it. The first is made to operate counter with the higher working voltage and the second t with the lower working voltage; the 100 V variation is qu adequate for the Philips halogen-quenched counters used

(b) *"Gating" circuits*

The output pulses from the dead-time correction circ are negative-going, and of amplitude 180 V. The "gatir stages (Fig. 3) are pentodes which provide from them positi going pulses of amplitude 30 V, large enough to operate first stages of the Dekatron scalers; application and remov of a cut-off bias on the suppressor grids of the pentodes used to determine the time interval during which the scale are counting. The bias change is brought about by t operation of a relay activated by the thyratron circuit de cribed below. The spurious positive-going pulses produc in each channel when the anode currents of the valves a switched off in this way are prevented from affecting t scalers by arranging that they are of only half the amplitu of the normal anode pulse. A Unistor (by Standard Te phones and Cables) is connected between the pentode scre and the midpoint of the anode load, and the values of t screen and anode resistors are chosen so that the scre potential has the same value whether the suppressor gr potential is that of the cathode, or such as to cut off t anode current. When the latter occurs, the half-size pulse obtained at the anode. The succeeding scalers are arrang to respond only to the full-size pulse.

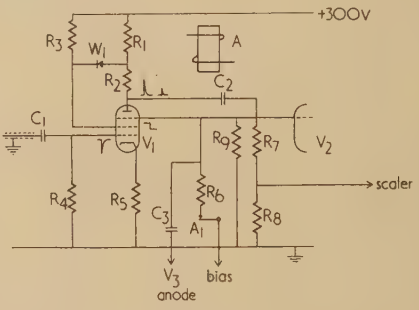

Fig. 3. Gating circuit for the scalers

R_1, R_2 = 33 kΩ
R_3, R_4 = 100 kΩ
R_5 = 470 Ω
R_6 = 120 kΩ
R_7 = 75 kΩ

R_8 = 30 kΩ
R_9 = 120 kΩ

C_1 = 50 pF
C_2 = 470 pF

C_3 = 0·2 μF
V_1, V_2 = 6AM6
W_1 = Unistor Q3/3
A = P.O. relay (Type 3000, 150 Ω

(c) *Thyratron switching circuit*

This is shown in Fig. 4. A relay A controls the applicatio of the bias to the suppressor grids of the "gating" circui through one of its contacts A_1; the relay is "locked up" f the bias to be lifted and the scalers to operate. A secon

B unlocks A when the last monitor scaler count is e. Relay B is in the anode circuit of a type 2D21 atron V_3 which is fired by the output pulse of the last atron. The operation of the two relays introduces a of some 25 ms in the re-application of the bias, and this ld permit the recording of counts which occur after the itor counts have ceased. This delay is avoided by ng a C–R coupling (C_3R_9) between the thyratron anode the suppressor grids of the "gating" valves. Its time tant is chosen so that the negative pulse, of amplitude 260 V, has decayed to a value approximately equal to of the bias (100 V) during the 25 ms mechanical delay, this prevents the quenching of the thyratron when the is applied again.

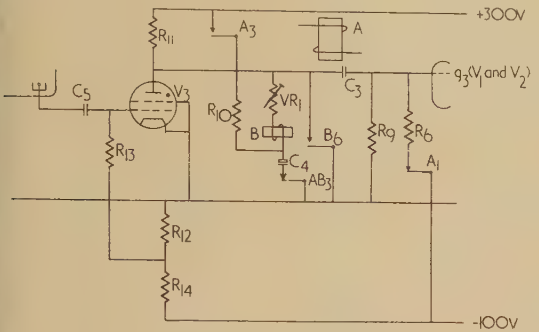

Fig. 4. Scaler-switching circuit

= 120 kΩ
= 120 kΩ
= 47 kΩ
= 1 MΩ
= 100 kΩ

R_{13} = 470 kΩ
R_{14} = 390 kΩ

C_3 = 0·2 μF
C_4 = 8 μF

C_5 = 0·02 μF
RV_1 = 50 kΩ
V_3 = 2D21
B = P.O. relay (Type 3000, 10 kΩ)

losure of the relay B also switches on a lamp to illuminate Dekatron escutcheons, operates the camera shutter, and ates the rest of the automatic sequence. The relay must l for the exposure time of the film (approximately one nd), and this is achieved by discharging an 8 μF capacitor ugh the relay B and a 50 kΩ preset resistor; the latter s a control of the exposure time. The capacitor is arged through a 47 kΩ resistor and the relay contact A_3 le the next count is being made. To prevent premature nching of the thyratron by the oscillations which occur he discharge process because of the self-capacitance of the , the firing pulse is made long enough to enable contact o close; this provides an alternative path for the discharge ent and, with the high resistance R_{11}, quenches the atron.

(d) *Background-setting circuits*

he counting-rate meter$^{(15)}$ uses a monostable multi-ator circuit to derive from each input pulse another of nite duration and amplitude. These pulses are applied pentode biased beyond cut-off, and each produces the e increment of charge on the integrating capacitor in the de circuit. Capacitors of different sizes are switched in allel to give a choice of time-constant. A meter M_1 (not wn in the diagram), fed by a cathode-follower circuit from integrating capacitor, indicates the counting-rate; the A chart recorder may be connected in series with this er. Variation of the duration of the pulses from the tivibrator by switching in different grid resistors gives scale deflexion of the meter for counting rates of 10, 30, 300 and 1000 counts/s.

he circuit for setting the background reference level is wn in Fig. 5; V_{4b} is a cathode-follower "buffer" input stage which obtains its grid potential from the cathode of the valve supplying the counting-rate meter M_1. There are two modes of operation of the circuit; in the first the background reference level remains fixed after setting it manually, but in the second an automatic arrangement maintains the reference level at a preset height above a monotonically decreasing background. In both cases the basic action is the same; the grid potential of the thyratron V_{11} is determined by either the manual or the automatic setting, and the cathode potential by the counting rate. As the counting rate increases, the cathode potential falls, and when the grid-cathode potential difference reaches a value determined by the thyratron anode voltage, the thyratron conducts, closing relay K and initiating the step-scanning sequence. The thyratron is "tested" for the conducting condition by the application of a 50 c/s anode voltage, the positive peak value of which is stabilized; the relay K, which is held between successive cycles by the action of C_{18}, can then open as soon as the non-conducting condition obtains.

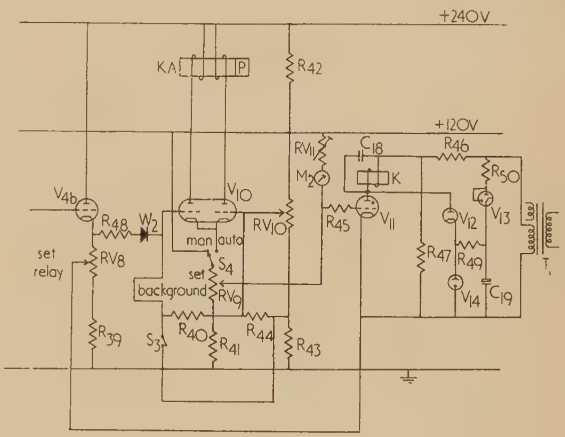

Fig. 5. Background-setting circuit

R_{39} = 100 kΩ
R_{40} = 1 MΩ
R_{41} = 15 kΩ
R_{42}, R_{43} = 33 kΩ
R_{44} = 4·7 kΩ
R_{45} = 390 kΩ
R_{46}, R_{47} = 5 kΩ
R_{48} = 25 kΩ
R_{49} = 10 kΩ
R_{50} = 2·5 kΩ

C_{18} = 0·25 μF
C_{19} = 32 μF

RV_8 = 20 kΩ
RV_9, RV_{10} = 10 kΩ

RV_{11} = 1 kΩ

V_{4b} = ½ 6SL7
V_{10} = 6SN7
V_{11} = GT1C
V_{12} = EA50
V_{13} = 6X5
V_{14} = VR90

K = P.O. relay (Type 3000, 10 kΩ)
KA = Carpenter polarized relay (T.M.C. Type 6B31)
T_1 = secondaries 6·3 V, 250 V
W_2 = Q3/3
M_2 = 0–50 μA

The stabilization of the positive peak value of the thyratron anode voltage is brought about by "clamping" the output of the transformer T_1 to a stabilized 90 V positive d.c. supply with the diode V_{12}; the 90 V supply is obtained in the usual way across the stabilizer tube V_{14}. The thyratron circuit "floats" with respect to earth, since the thyratron cathode potential is determined by the setting of RV_8.

Manual background setting. To assist in setting up the circuit, the meter M_2 is incorporated, and is adjusted to read the same as the meter M_1 in the counting-rate circuit by the following procedure. The switch S_4 is set to "manual," so that V_{10} is out of action. The Geiger counter is put out of action by disconnecting it, or by switching off its h.t. supply. The meter M_1 is made to read zero by its "set zero" control. Meter M_2 is made to read zero by rotating the "set background" control fully anticlockwise so that its slider is at the upper end of RV_9. The "set relay" control is now adjusted until relay K is on the point of operating; a lamp on the front panel lights when the relay has operated. The Geiger counter is reconnected, and X-rays are turned on to give a counting rate on M_1 near full-scale. The "set-background" control is now adjusted to make M_2 read the same as M_1, and to maintain this condition while RV_{11} is altered until the relay K is again on the point of operating. The circuit is now in adjustment, and when the chosen background counting rate has been set on M_2 by the "set-background" control, relay K will operate when the rate is exceeded, and release when it is not.

Automatic background setting. The operation of this circuit is made possible by the fact that in most patterns the actual background is a maximum at low angles and decreases gradually over the recorded range. With the switch S_4 set to automatic, the upper end of RV_9 is held at the potential which is common to the grids of the double cathode follower V_{10}. A small servo-system maintains the grids at the same potential in the following way. The wire-wound potential divider RV_{10} has no end stops, so that the slider may be rotated continuously; the presence of R_{44} avoids discontinuity while the slider negotiates the gap in the track. The control shaft is geared to a small d.c. motor which drives it in one direction only so that the slider moves towards the high-potential end of the track. The sensitive polarized relay KA (Carpenter type 6B31) operates the motor (*via* a slave relay) when the currents in the two coils and hence the grid potentials of V_{10} differ, and the motor runs until balance is regained. A reduction gear train ensures that the control shaft takes several seconds to rotate once, so that "overshoot" when the motor is switched off is negligible. If the actions of the rectifier W_2 and the switch S_3 are neglected, it follows that the slider will be stable in any position which it takes up, since the two grids are connected by the high resistance R_{40}. Closure of the switch S_3 will evidently cause the slider of RV_{10} to run to the lowest position; if S_3 is then opened, the slider will move (upwards) only if W_2 conducts, i.e. if the cathode potential of V_{4b} rises above the common grid potential. Such a change corresponds to a decrease in counting rate, so that the grid of the thyratron V_{11} follows its cathode when the counting rate falls. An increase of counting rate lowers the cathode potential of the thyratron, but the grid potential remains fixed; the thyratron will come into conduction when the cathode potential has fallen far enough. The setting of RV_9 ("set background") determines how far the counting rate corresponding to the grid potential must be exceeded before relay K operates and step-scanning starts.

The circuit is set up in two stages. Zero-setting adjustments are first made without the Geiger counter in operation. Switch S_3, which is coupled to the shaft of VR_9 and closes when the slider potential is a maximum, is operated, and the servo-motor runs the slider of RV_{10} to its minimum position. The shaft of RV_9 is then rotated to open S_3, and the rotation is continued until M_2 registers zero current; the "set-relay" potentiometer RV_8 is then adjusted until relay K is on the point of operating. To set the circuit for operation, the Geiger counter is reconnected, and the goniometer set at its starting-point with X-rays on. The counting-rate meter time-constant is set at a fairly high value, and the meter M_1 is allowed to become steady. The actual position of the counter, whether on line or background, is immaterial, except that if it happens to start on the descending slope of a line, that line will be neglected. The slider of RV_{10} is brought to minimum potential by opening S_3 as before. The shaft of RV_9 is then rotated to close S_3 and increase the current through M_2 until its reading coincides with that M_1. The relay K, which has been holding since the X-ra were turned on, now releases. The shaft of RV_9 is furt rotated until the required preset height above background indicated by the difference between the two meter readin The circuit is now set, and will adjust itself to maintain reference level at the chosen height above a background wh is decreasing monotonically.

(*e*) *Sequence control circuits*

The data supplied to the control circuits in the equipme is step-like in character, and not continuous. For examp scalers are on or off, the camera shutter is open or close the goniometer-drive motor is running or not running, a so on. The control circuits produce from such informati closed or open paths interconnecting the various elements the apparatus. Since the majority of control conditions a two-valued, the bistable electromagnetic relay is us extensively in such circuits; it is well suited to the expressi of the logical relationships which are the basis of switchi circuits of the type used. An output circuit which requires coincidence of input conditions may be established by co necting relay contacts in series, while one which requires o condition out of many may be established by contacts parallel. The use of relays in such arrangements and t circuit design procedures have been dealt with in the liter ture.(16) In this section their application to the prese instrument is given in outline only; the authors are prepar to supply full circuit details, sequence charts, and time cha to those interested.

In addition to their use for establishing control paths, t relays have two other useful applications. They may made to give only a momentary contact at the instant wh an operating path is closed, though it remains closed ther after, and they may be made to close or open contacts considerable time after closure of the operating path. The results are achieved by the use of capacitors, charged from high-voltage supply, and discharged appropriately throug the relay coil; high-resistance low-current relays are co veniently used in such circuits. Fig. 6 shows a "flick" circu and a "delay" circuit of this type. In the "flick" circui closure of the contact B_1 (usually on another relay operates relay A for a time which depends on the magnitud of the capacitor and its high-voltage supply and on th characteristics of the relay. The resistance R limits th resulting steady current to less than that required to releas the relay; the repetition frequency of the action is limited b the time constant of the capacitor-charging circuit. If th

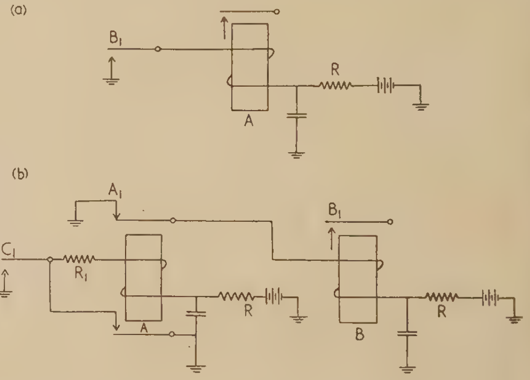

Fig. 6. Relay circuits (*a*) momentary contact; (*b*) delayed momentary contact

tact B_1 is normally closed, operation of relay *B* (for a ε sufficient for the capacitor to charge) will "flick" relay when *B* is released. In the first "delay" circuit the nentary "flick" of *A* is lengthened by the inclusion of a able resistance R_1 in the capacitor discharge path; the tact A_1 operates relay *B* in the second type of "flick" uit, so that contact B_1 closes momentarily at an appro- .te time after the closure of contact C_1.

ince the present control arrangement is one in which the ε sequence of the input data, as well as their particular ıbination, determines the output, identical input com- ıtions may require different output conditions at different ɛs. To deal with such situations it is necessary to introduce ımber of "secondary" relays.

nput signals. Each of the modes of operation outlined ier is initiated by a push-button, and the operation of the ches associated with them provides input signals for the uence control unit. In addition to these, other input data, erated outside the unit, are used. They are derived from elay *B* on receipt of the final monitor count; (ii) relay *K* he background reference-level circuit; (iii) a microswitch nting the revolutions of the shaft which drives the Geneva ıpement for "stepping" the goniometer arm; (iv) the put of the counting circuit controlling the number of ›s taken by the goniometer arm in sequence *A* (back- und discrimination); (v) the "stop" button and safety ices for stopping the action. The first two of these have ady been considered; the essential features of the other ɛe will be described next.

he goniometer is driven by a 12 V reversible series-wound p. motor, which is mounted on the same chassis as the ers and angle marker; a flexible drive couples the motor the goniometer through a magnetic clutch, which is tched with the motor and allows it to "run down" lutched from the rest of the mechanism. Between the ch and the flexible drive are the angle marker and the ı-operated microswitch. The operation of the micro- tch "flicks" a relay *D* once per revolution of the drive ft. According to the sequence in use, and the conditions aining at the time, the contacts of relay *D* must permit the tor to be driven one, ten or twenty steps. A Dekatron le-of-ten circuit, preceded when necessary by a relay scale- wo, operates through the contacts of relay *D* to give a se on relay *I* at every tenth or twentieth step. The katron output pulse operates relay *I* by means of a ratron circuit similar to that which operates relay *B*. ε Dekatron is reset to zero by a contact on the "start" ton for the *A* sequence; the thyratron is prevented from ıg while this is being done.

he relay scale-of-two is shown in Fig. 7. It may be ısidered as actuated by pulsing the single contact *S*, ugh the latter is actually a combination of relay contacts. the normal state neither of the relays *AM* and *BM* is rgized; capacitor C_{28} is discharged and short-circuited *via* $_2$ and the resistor R_{68}. The first pulse on *S* operates , which "locks up" on AM_1 *via* BM_1; C_{28} now charges AM_2 and R_{69}. Thus the next pulse on *S* causes *BM* to ck," breaking BM_1, releasing *AM*, and restoring the tem to the original state. The relay *BM* is adjusted to e a large difference between operating current and holding rent, and R_{69} is chosen so that *BM* will hold without istance from the capacitor but will not operate without it; supply for *BM* is taken from the stabilized 300 V line. en *BM* "flicks" C_{29} gives a pulse to the Dekatron; if G_3 losed, so also does the operation of *AM* by the action he continuity-transfer contact AM_3. Thus G_3 determines whether ten or twenty pulses have to be received *via S* before the Dekatron operates relay *I*.

The sequence of operations may need to be stopped by the push-button on the front panel, by one of the goniometer limit switches or by the running out of the film in the camera. Since the "stop" action must persist for long enough to allow the large capacitors in any delay circuits which are in operation to discharge, the "stop" signals are arranged to operate a relay *Z* which holds, by a delay circuit, for the required length of time. The contacts of the relay disconnect the power supplies from all relays; if it has been brought into action by the limit stops or by film exhaustion a small neon lamp flashes on the goniometer or the camera.

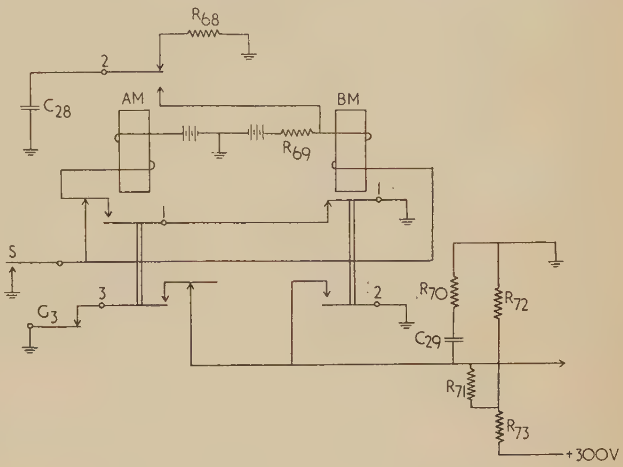

Fig. 7. Relay scale-of-two circuit

R_{68} = 100 kΩ
R_{69} = 200 kΩ
R_{70} = 100 Ω
R_{71} = 2·2 MΩ
R_{72} = 390 kΩ
R_{73} = 470 kΩ
C_{28} = 0·5 μF
C_{29} = 0·05 μF
AM, *BM* = P.O. relays (Type 3000, 10 kΩ)
G_3 = selector contact (open for scale-of-two)
S = operating switch

The operation of each relay in the control unit is arranged to light a small neon lamp on the front panel of the unit, so that a ready check of the performance of the circuits is available.

Circuits controlled. The establishment of each output control path brings into action at the appropriate time various electrical or electro-mechanical devices. These bring about:

(i) the starting and stopping of the counting process by application of bias to the suppressor grids of the "gating" valves;

(ii) the illumination of the escutcheons of the Dekatrons of the scaler circuits while they are being photographed. This is brought about by short-circuiting a resistance in series with the tubular tungsten lamp which gives the illumination. The value of the resistance is such that the lamp is just out in the normal condition;

(iii) the operation of the solenoid which controls the single-leaf box-camera type shutter on the camera;

(iv) the movement of the film in the camera by one frame after exposure. For this action closure and release of a single "make" contact is required; film transport takes place on release. Further details of the film-winding action are given later;

(v) the operation of the frame counter, which indicates on the front panel the length of film used. The counter is a modified Post Office register, geared to indicate in centimetres the length of film used, and operated by discharging a capacitor through the coil.

(vi) the switching of the motor driving the goniometer arm. The circuits already described close a relay for the appropriate running time; this relay operates a "slave" relay with heavy-current contacts which control the motor and the magnetic clutch. The direction of rotation of the motor, which in the *A* sequence may be in either direction, is controlled by an appropriate combination of relay contacts. A resistance across the contacts of the centrifugal governor on the motor acts as a spark suppressor, and the motor control contacts are also fitted with spark-suppression components;

(vii) the resetting to zero of the three scalers and the motor-control Dekatron. This is achieved in the usual way by breaking a contact across a resistance so that the potential difference developed across it raises the potentials of the guides and of cathodes 1 to 9 by about 100 V. The monitor and specimen scalers are always reset together by a common contact; the integrating scaler uses a separate contact. The resetting of the motor-control Dekatron has already been described;

(viii) the operation of the solenoid which moves the film mask in the camera at the end of a line to allow the integrating scaler indication to be photographed. (A recent modification allows both scalers to be photographed on each frame, this has proved useful for centre-of-gravity determination

(ix) the closure of contacts indicating on a three-colo lamp on the front panel the sequence being followed. T lamp is off for semi-manual operation.

Circuit development. The simpler of the two step-scann sequences, sequence *B*, will first be considered; it may regarded as a sub-section of the more complicated sequence in which background discrimination takes place. The list input, secondary and output operations in sequence *B* given in Table 1.

The delay before starting the scalers is required for the sequence. The motor is arranged to start after the pho graphic exposure has been made to minimize the effect shake on the resolution of the photograph. The sequen chart for the control circuit, shown in Fig. 8, interprets t

Table 1. *Operations in sequence B*

Input	*Secondary*	*Output*
Push-button "start *B*"		Reset scalers; indicator lamp on
	Delay	
		Start scalers
Monitor output		Stop scalers and hold
	Timing circuit (relay *B*)	Light on and shutter open for 1 s, and release
		Frame counter, film traverse and release
		Drive motor switched on and held
Motor shaft completes 1 revolution		Motor off
	Pulse to recycle	

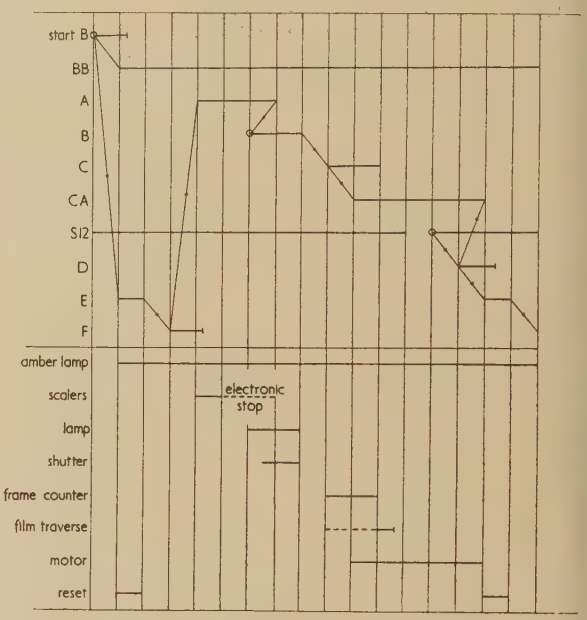

Fig. 8. Sequence *B*; sequence chart

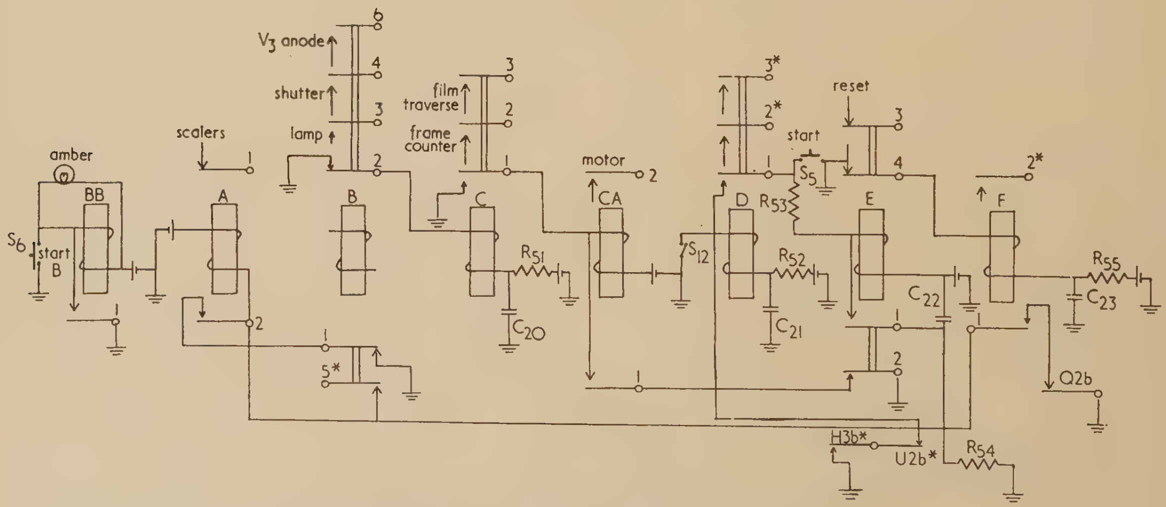

Fig. 9. Sequence *B*; relay circuits

(Contacts marked * are used only in sequence *A*.)

R_{51} = 130 kΩ
R_{52} = 200 kΩ
R_{53} = 47 kΩ
R_{54} = 590 kΩ
R_{55} = 390 kΩ
C_{20} = 1 μF
C_{21} = 0·35 μF
C_{22} = 8 μF
C_{23} = 0·5 μF
B, C, D, E, F = P.O. relays (Type 3000, 10 kΩ)
A, CA, BB = P.O. relays (Type 3000, 150 Ω)

n terms of the relays required to perform each operation, wing for operate and release times. The sequence may ollowed by the arrows; the circles on the chart indicate re the input signals occur. Relay *D*, in addition to giving output signal for stopping the drive motor, also performs secondary function of providing a pulse to recycle the uence. The relay circuits previously described are now rconnected as shown in Fig. 9 to give the required action. contacts marked with an asterisk function only when uence *A* is in operation.

equence *A* is developed in a similar way. The list of rations required is given in Table 2. From this list the

Table 2. *Operations in sequence A*

Input	*Secondary*	*Output*
h-button "start		Zero motor Dekatron. Indicator lamp on
Relay *K* out	Scale of ten	Motor on (forward)
tor shaft completes 10 revolutions		Motor off
	Delay	
	Pulse to recycle	
K out		Recycle to (*a*)
K in		Sequence (*b*) below
K in	Scale of twenty	Motor on (reverse)
tor shaft completes 20 revolutions		Motor off
		Start sequence *B*
	Scale of twenty	Sequence *B*
ompletion of 20 s of sequence *B*	Counting circuit stopped	Sequence *B*
ut	Scale of ten	Sequence *B*
npletion of 10 s of sequence *B*		
K in		Recycle to *
K out		Stop sequence *B*
		Move film mask
		Traverse film
	Timing circuit	Light, shutter
		Film traverse
		Reset integrating scaler
	Scale of ten	Motor on (forward)
tor shaft completes 10 revolutions		Motor off
	Delay	
	Pulse to recycle	
K out		Recycle to (*a*)
K in	Scale of ten	Recycle to (*b*) but reverse ten steps only

ailed circuit design is evolved along the lines already sidered for sequence *B*. Shortage of space precludes lication of an account of it here, but it may be obtained m the authors as already indicated. The continuous-scan uence *C* and the semi-manual sequence *D*, which require tively simple relay circuits, and the peak-only step-scan *E*, ch is a slight variation of sequence *A*, are also omitted.

(*f*) *Camera circuits*

n addition to the interchange of signals between control t and camera considered above, circuits are required to trol the film-winding processes which occur when the camera is removed or inserted. The construction of the camera is such that when it enters its housing in the control rack a "leader" of at least four inches of film must be wound on before photographs may be taken, and that before removal of the camera a "trailer" of film of at least eight inches must be wound on. Since such lengths of film contain a large number of frames, omission of either winding process would spoil considerable parts of the record. The possibility of this is avoided by making both processes automatic; a push-button operated by the back of the camera when it is fitted into the rack initiates the winding-on of the leader, and removal of the camera from the rack is prevented until the winding-on of the trailer, initiated by a push-button on the front of the camera chassis, is completed.

Internal circuits. The ten connexions between the camera and the main chassis are made by a multiple plug at the back of the camera. The internal circuits are shown in Fig. 10. The shutter and film mask operate when power is supplied to their actuating solenoids. The film winding is carried out with an impulse motor; the armature return-springs drive a ratchet when the armature is released. The circuit ensures full movement of the armature in both directions, and operates as follows. When the power supply is connected, the armature operates, and a contact on it opens the shunt path across relay *HP*. Its operation opens HP_1 disconnecting the motor coil and releasing the armature, and also opens HP_2 and hence the shunt path across the relay *IP*. The current through this relay builds up according to the time constant of the delay circuit until *IP* operates. Then IP_1 releases *HP*, reconnecting the shunt path across *IP* and discharging capacitor C_{42}, and also reconnecting through HP_1 the supply to the impulse-motor coil. The cycle then repeats until power is removed. The delay circuit ensures that the motor runs at a rate suitable for satisfactory film winding. For single-frame winding the power supply is connected directly across the impulse-motor coil; the film is traversed when the supply is disconnected.

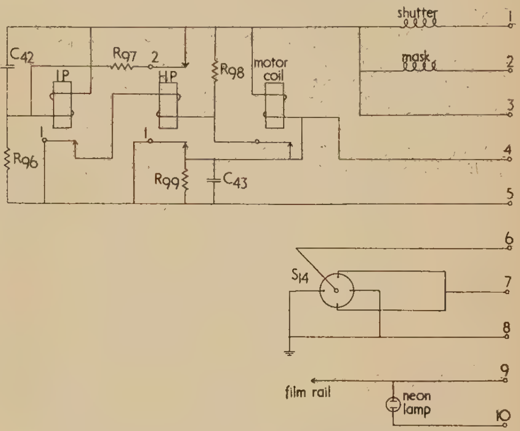

Fig. 10. Circuits within the camera

$R_{96} = 1\ \text{k}\Omega$
$R_{97} = 250\ \Omega$
$R_{98} = 200\ \Omega$
$R_{99} = 18\ \text{k}\Omega$

$C_{42} = 250\ \mu\text{F}$

$C_{43} = 8\ \mu\text{F}$

S_{14} = rotary switch

IP, *HP* = P.O. relay (Type 3000, 150 Ω)

The shaft of the impulse motor is coupled directly to the film-transport sprocket, and also to a rotary switch S_{14}. This gives a momentary contact to earth from pin 6 once every quarter revolution of the sprocket if pin 7 is earthed, and once every half revolution if it is disconnected. These contacts are used to control the winding-on of the film "leader" and "trailer."

The neon lamp which gives warning that the film is exhausted operates when the pressure plate at the back of the film, which is insulated from the camera body and connected to pin 9, comes into contact with a pair of guide rails in front of the film and connected to earth.

External circuits. These are concerned with the automatic film-winding and the locking of the camera in the rack. A locking bar prevents the camera from entering the rack unless the power supplies are on; lighting of a green lamp indicates that this condition is fulfilled. Insertion of the camera then operates a push-button as it goes fully home and this starts the impulse motor and keeps it running until the film sprocket has completed at least half, or at most three-quarters, of a revolution. This corresponds to winding on a length of film between four and six inches long. The locking bar is actuated, and holds the camera in the rack while a record is being taken, and until a sequence of operations initiated by a push-button on the front panel is concluded. In this the film sprocket is rotated by at least one, or at most one and a half, revolutions, and between eight and twelves inches of film are wound on. A red lamp then lights, and the locking bar lifts so that the camera may be withdrawn. Since the bar locks the camera when its operating solenoid is not energized, the camera cannot be accidentally withdrawn with the power supplies to the equipment off.

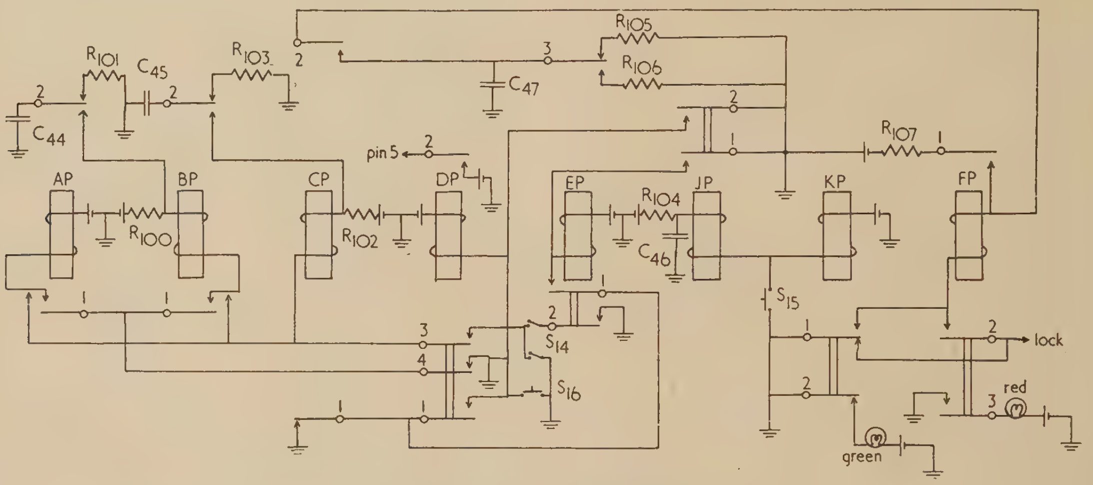

Fig. 11. Circuits for camera control

R_{100} = 200 kΩ
R_{101} = 10 kΩ
R_{102} = 150 kΩ
R_{103} = 10 kΩ

R_{104} = 200 kΩ
R_{105} = 2 kΩ
R_{106} = 2 kΩ

C_{44} = 10 µF
C_{45} = 8 µF
C_{46} = 8 µF
C_{47} = 250 µF

S_{14} = rotary switch
S_{15} = switch operated by insertion of camera
S_{16} = camera release button

AP, *DP*, *EP*, *KP* = P.O. relays (Type 3000, 150 Ω)
BP, *CP*, *JP*, *FP* = P.O. relays (Type 3000, 10 kΩ)

Fig. 11 shows the circuit used. The relays *AP*, *BP* and *CP* form a scale-of-three counting circuit, similar to the scale-of-two of Fig. 7, but with one extra stage. It is operated by the pulses from the rotary switch on the film sprocket, so that the third pulse received after the winding starts will occur after the required length of film has been wound on irrespective of the initial position of the switch.

When the camera is pushed home in the rack, S_{15} makes and holds. Relay *JP* flicks, and relay *KP* operates and holds, de-energizing the locking solenoid and extinguishing the green lamp. The momentary contacts on JP_1 and JP_2 bring in relays *DP* and *EP*, which lock up on contacts DP_1 and EP_1 respectively *via* CP_1. Contact DP_2 makes and supplies power to the impulse-motor circuit, which runs until the third pulse from the rotary switch flicks *CP*. Contact CP_1 then releases *DP* and *EP*, and DP_4 releases *AP* and The circuit is now in its original state except for relay which is still held by S_{15}.

The camera release button closes S_{16}, which brings in locks up *DP* alone. The counting circuit is now opera every half revolution, since EP_2 is open. When *CP* opera the winding is stopped, *DP* releases, and CP_2 brings in re *FP via* EP_3. Relay *FP* locks up on FP_1 *via* KP_1, the cam lock is released, and the red lamp is switched on. Withdra of the camera opens S_{15}, *KP* releases and releases Contact KP_1 is now closed and keeps the locking bar lif the red lamp goes out and the green lamp comes on. circuit is now ready for reinsertion of the camera. A pu button on the front panel of the sequence control u operates a switch which gives manual control of the s running impulse motor circuit. The film may then be wo on a few frames between successive runs when necessary.

(*g*) *Power supplies*

The power supplies for the equipment are obtained fr conventional circuits, and are as follows:

d.c.	450 V	310 V	250 V	—120 V	24 V	12
	stabilized					
	7 mA	170 mA	20 mA	40 mA	0·2 A	5 A
a.c.	6·3 V	6·3 V	6·3 V	4·0 V	4·0 V	
	1·6 A	1·9 A	10 A	3·75 A	1·0 A	
Potential above earth	310 V	120 V	zero	500 V	120 V	

MECHANICAL AND OPTICAL DETAILS

Goniometer drive. In the original goniometer a sm synchronous motor was used to drive both the continuou scanning and the step-scanning gears, but this arrangeme has been modified to allow a separate and much fast running motor, for use with the step-scanning gears, to placed in the main rack where the magnetic clutch, ang marker and cam-operated microswitch are most convenient located. The flexible drive from this motor is left pe manently connected to the shaft driving the Geneva escap

: which gives the "stepping" action. The small synchron- motor on the goniometer itself is mounted in such a way its driving shaft may also be left permanently in place; haft is brought in at the same radial distance from the n shaft as is the first, so that the interchanging of the s permits the ready use of either driving shaft to rotate vorm which turns the main goniometer gearwheel. The n may be rotated directly without turning the flexible by first operating a clutch on the goniometer and then a handle on the end of the shaft. This facility is ired for rotating the goniometer quickly through large es, e.g. for resetting at the end of a run.

e driving arrangements in the main rack are shown matically in Fig. 12. The angle-marking counter is an ptation of a five-digit revolution counter (by Trumeter which has large clear figures easily legible on a photo- h. The last two digit wheels have been unriveted from driving gears and refixed on the opposite sides so that reading may be interpreted directly as an angle given to

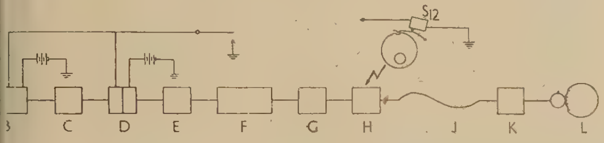

Fig. 12. Goniometer drive

governor; *B*, motor; *C*, worm drive 40 : 1; *D*, magnetic itch; *E*, bevel gear 1 : 1; *F*, angle counter; *G*, helical gear 1; *H*, stepping switch; *J*, flexible drive; *K*, bevel gear 1 : 1; *L*, Geneva escapement.

decimal places; a space occurs at the position of the mal point. The resetting lever has been adapted as a utching lever, and is coupled mechanically to a knob on front panel. If the goniometer has been rotated while onnected from the flexible drive, the counter must be t manually to read the same as the angle indicator on the iometer itself, and this is done directly by rotating the nter wheels with the fingertips after declutching.

he shaft which operates the flexible drive carriers the cam which bears a brass spring; this actuates the microswitch per revolution. The switch is closed while the spring anywhere in the marked sector of the cam, including the h. The slight mechanical pressure exerted by the spring he drive shaft *via* the notch is sufficient to ensure that the em always comes to rest in the same position. Two s are needed, one for the forward and the other for the rse motion. A portion of the second cam is cut away llow the first to work, and the two cams are bolted ther through a slotted hole to give a small adjustment heir relative positions. They are set so that the last digit e angle marker is in line with the others when the system es to rest. A less critical arrangement would be possible e last digit wheel of the angle marker were to rotate in s from digit to digit instead of revolving continuously.

ptical arrangements. The optical path from the face of Dekatron scalers to the camera lens is shown in Fig. 13, ch is a side elevation of the rack showing a section at the ral plane. The scaler faces are set back from the front els and a 45° front-silvered mirror sends the light from n vertically downwards into the lens through gaps in the e intervening chassis. The mirror is mounted at the k of a Duralumin panel, and is located by the flush ng of this panel to the front panel of the scaler chassis. position and location of the mirror are not over-critical because of its proximity to the scaler faces. The mirror is easily removable when visual recording is required.

Camera construction. The camera is a rectangular box made of Duralumin, with a dividing partition separating the film from the impulse motor and its accessories. The side panel on the film side forms a removable door for loading and removing film; rotation of a handle on this door operates two bolts which lock the door to the body of the camera. The take-up cassette in the camera is coupled by a pin to a slot on the inside part of the handle. This is done in such a way that opening the door closes the cassette, and *vice versa*, so that the film is protected from accidental exposure.

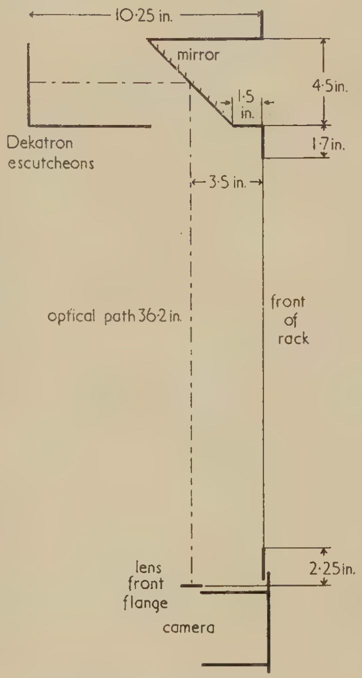

Fig. 13. Optical path between scalers and camera

The lens used is from an ex-R.A.F. ciné-camera, and has a focal length of 1½ in. and a full aperture of $f/4$. A small push-fit aluminium cap on the end of the lens-mounting tube reduces this to the working aperture of $f/12$. The arrangement covers adequately the ⅝ in. frame width required. A small focusing adjustment is provided by fitting the lens into a threaded aluminium tube, but once set no further movement is required. The lens protrudes slightly above the top face of the camera, and two ebonite runners on each side of it protect it when the camera is inserted into or withdrawn from the rack.

The solenoids operating the mask and shutter are made by removing the cores from two type 3000 P.O. relays, and replacing them by thin-walled brass tubes containing soft-iron plungers. These are linked to the shutter and mask by stout wire loops. The box-camera shutter, the return spring of which has been strengthened, is mounted on a thin Paxolin board immediately beneath the lens. The hole in the mask is cut to the exact frame size (0·075 × 0·625 in.) and is moved by the solenoid exactly 0·080 in. in its slot in the film rail. The distance is adjustable by two grub screws which engage a pin on the mask; they lie in a U-shaped brass mounting bolted across the film rail. The distance moved by the mask corresponds exactly to the distance between the centres of the images of the two scalers on the film, and the width of the frame allows the two scalers to be recorded on consecutive frames with a distance of 0·005 in. between them. The film traverses 0·080 in. each time the impulse motor is energized, so that the same distance of 0·005 in. occurs between the consecutive frames of a run. Fig. 14 shows a reproduction of a typical record. Two Perspex inserts on the film rail prevent sideways contact between the pressure plate, the springs of which are fixed to insulated supports, and the camera body; contact can only be made when no film is present.

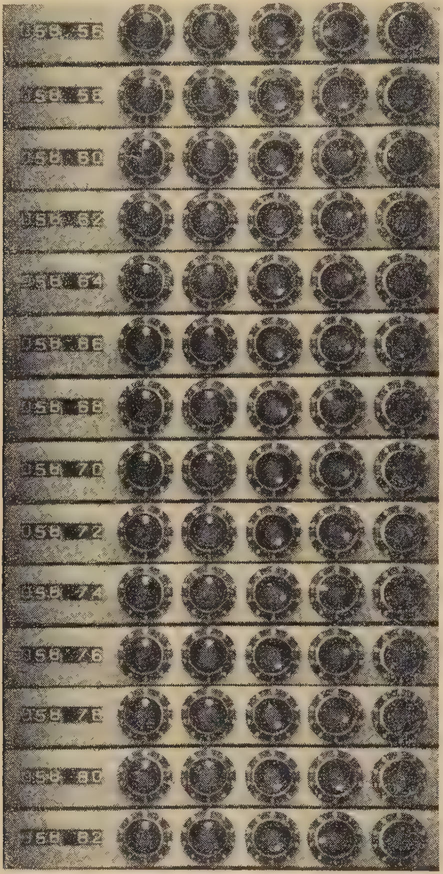

Fig. 14. Part of a typical camera record

The take-up cassette consists of a brass spool which is housed in two cylindrical brass cases; these fit over one another to form a light-tight cylindrical container. Each case has an axial slot in the curved portion through which the film passes; rotation of the slots into and out of coincidence opens and closes the cassette. The film is attached to the spool by means of adhesive tape rather than by using a slot arrangement. Insertion of the cassette into the camera engages a pin through the hollow centre of the spool with a slot on the driving shaft, and also engages three locating pins on one end of the cassette with corresponding holes in the central partition of the camera. The other half of the cassette may then be rotated relative to it by the action of the door handle as already explained.

The store cassette contains 200 ft of film, and is constructed by fitting a velvet light-trap to a normal film-delivery canister. The amount of film present in the store is indicated by the rotation of a shaft which passes through a light-tight bearing in the wall of the cassette; the shaft carries an arm which is caused to bear against the film
an external spring. The shaft is coupled to an indicato
the front panel by a suitable linkage. The indicato
formed by having a cylindrical brass shell attached to
inside of the panel, and a movable coaxial section behin
The latter is viewed through a hole cut through the pa
and the fixed shell, and it is rotated by the movement of
arm in the cassette. A velvet pad is stuck to the insid
the outer shell, and the inner one bears against it to keep
camera light-tight. The state of the store is indicated
marks engraved on the inner shell.

The film-transport mechanism is driven by a Post O
impulse motor which takes 104 steps per revolution.
shaft of the motor passes into the film compartment
carries the film-driving sprocket and a pulley wheel.
latter drives the take-up spool by means of a slipping ba
the pulley diameters are chosen to give the minimum amo
of slip. The film-driving sprocket is constructed so tha
has forty-five teeth at a distance apart of 0·187 in.,
distance between successive perforations in the 35 mm fi
The sprocket radius is 1·34 in., and this gives to a very cl
approximation a circumferential movement of 0·080 in.
impulse for traversing the film.

The consistency of the movement required for a legi
record is not high, as the gap between frames is reasona
large compared with the frame width, and a slight ov
lapping of the frames would affect the legibility of the rec
but little. However, the mechanism has been made as ri
as possible and the impulse motor shaft has been ma
stronger in order to obtain an even spacing between
frames.

The film chosen for recording is Kodak Plus-X "Walk
Picture" film, which is designed for applications wh
hardness and physical strength are as important as emuls
quality. The panchromatic emulsion has a spectral respo
suitable for recording both the blue high-speed Dekatr
and the slower red Dekatron without a balancing filter, a
the grain is sufficiently fine to obviate the need for
expensive microfilm ultra-fine-grain developer.

A special film reader has been designed for rapid and ea
reading of the records. The film may be moved one fra
by depressing a lever, or may be motor-driven for mov
from one part of the record to another or for rewindi
The picture is projected on a screen which may be read
table-surface height for convenience when plotting results
a graph or transferring them to a calculating machine. T
projected picture shows three adjacent frames of the reco
the centre frame is uncoloured, and the two others a
viewed through orange filters. Though the centre frame
the one normally being read, it is often useful to be able
see the preceding and succeeding frames at the same time.

CONCLUSION

The instrument has been in almost continuous operati
for more than two years, and has been used to obtain accura
data both for the A.S.T.M. Powder Data File and for ot
investigations in which detailed line profiles were required.
During the whole of this time it has proved very reliable bo
mechanically and electrically.

ACKNOWLEDGEMENTS

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by grants from the crystallographic data fund held in tr
by The Institute of Physics. The authors wish to expre

appreciation of the way in which the workshop staff he Physics Department, particularly Mr. J. G. Morris, sted in the detailed design and construction of the pment.

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Galvanometer feedback systems

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The principles of applying feedback to a galvanometer, after optical and electronic amplification, are discussed. In particular, the galvanometer performance is examined when proportional differential, compound and selective feedback systems are used. The latter method is compared with mechanical and series-capacitor tuning of the galvanometer response.

the amplification of small voltages of relatively low uency and from sources of low impedance, the galvano-er is still the most useful and widely used instrument. main disadvantage of the galvanometer has been its sitivity to vibration, but with modern anti-vibration untings, such as those used by Hill,(1) this can be reduced negligible proportion. The advantages are its simplicity, satility and sensitivity. The present paper is principally cerned with the second of these qualities and, in par-lar, how optical and electronic amplification combined n feedback can be used to modify the galvanometer formance.

schematic diagram of the galvanometer amplifier is wn in Fig. 1. Circuits of this type have been extensively d by various workers, notably Hill,(1) and many factors olved in their practical design are discussed by Jones.(2) light from a tungsten filament 36 W bulb at S is focused by a simple lens system on to the galvanometer mirror. The reflected beam is adjusted to half cover each face of a type CMV 28 twin photocell. Variation of the signal voltage into the galvanometer deflects the light across the photocells, and the resulting output is amplified by two balanced type EF 37A valves, connected as cathode followers. Further sensitivity can be obtained by connecting the amplifier in the manner described by Copeland, Downing and Hill,(3) or by interposing a double grid system in the light beam as described by Jones.(2) Part of the output across the terminals XX' is fed back through the network B (see below) to the input.

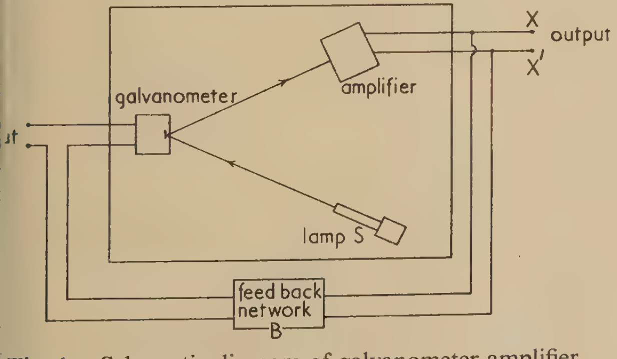


Fig. 1. Schematic diagram of galvanometer amplifier

GALVANOMETER EQUATION

Before discussing the effect of feedback on the galvanometer performance, it is necessary to briefly review the equation of motion of the suspended coil. The mechanical forces are balanced by the electrical couple according to the equation

$$I(d^2\theta/dt^2) + \alpha(d\theta/dt) + c\theta = Gi \qquad (1)$$

where I is the moment of inertia of the suspended system, θ the angular deflexion, α the damping due to air resistance, etc., c the elastic resisting torque per unit angle of displacement, and i the current. The constant G is given by the product of the area of the coil, the field strength and the number of turns in the coil. With no feedback, if the voltage instantaneously applied is e and the total resistance in the circuit R_T, the current is

$$i = \frac{1}{R_T}\left(e - G\frac{d\theta}{dt}\right) \qquad (2)$$

The solution of these equations for the variation of θ with time t depends on the ratio $[\alpha + (G^2/R_T)]^2/4Ic$. When it is unity, the system is critically damped and θ attains its steady value in the shortest time, as given by equation (3). Such a curve of deflexion against time for the Downing–Hill(1, 4) type of galvanometer used in the following experiments is shown in Fig. 2.

$$\theta = \frac{Ge}{cR_T}\left[1 - \varepsilon^{-t\sqrt{(c/I)}} - \sqrt{\left(\frac{c}{I}\right)} \,.\, t \,.\, \varepsilon^{-t\sqrt{(c/I)}}\right] \qquad (3)$$

It can be seen that the steady state deflexion is inversely proportional to R_T, and the increase in R_T necessary to obtain critical damping correspondingly reduces the sensitivity.

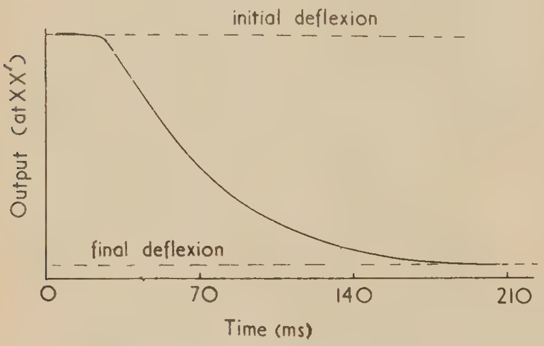


Fig. 2. Response curve, no feedback, galvanometer critically damped

$R_T = 21\ \Omega$. Output voltage/input voltage $= 3{\cdot}74 \times 10^6$.

PROPORTIONAL FEEDBACK

The output across the terminals XX' is proportional to the angular displacement θ, and the simplest form of feedback is to return a fraction of this into the input circuit. Two main forms of feedback loop can be devised as illustrated in Figs. 3(*a*) and (*b*). Type 3(*a*) has been used by Schmitt,(5) Preston(6) and Hill and others(3, 7) where the feedback is applied across the galvanometer; a preliminary analysis of its effect on the galvanometer performance was given by Hill in an appendix to a paper by Watton.(8) T currents in the two loops are given by:

$$e = Ti_1 + G(d\theta/dt) + S(i_1 - i_2)$$
$$A\theta = i_2(F + P) - G(d\theta/dt) - S(i_1 - i_2)$$

where e and T are the source voltage and resistance resp tively, $A\theta$ and P the output voltage and impedan respectively, S the galvanometer resistance, F the feedba resistance, and i_1 and i_2 the respective loop currents. T factor A is the gain in output volts of the optical-electro amplifier per unit angle deflexion of the galvanometer. T current i_1 can thus be expressed as:

$$i_1 = \frac{Qe - (F + P)G(d\theta/dt) + SA\theta}{Q(T + S) + S^2}$$

where $\qquad Q = F + P + S$

Though the current through the galvanometer $(i_1 - i_2)$ decreased by the feedback, the current i_1 taken from t source is considerably increased. The magnitude of th change can be more easily calculated by considering t steady state conditions when θ is proportional to $(i_1 -$ The reduction of input impedance (a typical figure of 0·14 is quoted by Preston(6)) increases the Peltier effect on a thermocouple connected to the circuit, unnecessarily decrea ing the sensitivity, it can be harmful if used in conjunctio with the Schwarz type detector, for which some of the lat circuits were designed. For this reason attention has be concentrated on the circuit of type 3 (*b*).

Circuits of the type, which include an auxiliary resistan R in the galvanometer loop across which the feedback applied, as illustrated in Fig. 3 (*b*), have been described Watton,(8) Gall,(9) Lawson(10) and Frankenhauser MacDonald,(11) but no complete circuit analysis has be given. This can be obtained by considering the output the amplifier as proportional to the deflexion θ and applyi Kirchoff's laws to the circuit Fig. 3 (*b*). The respecti currents are given by

$$e = i_1(T + S) + G(d\theta/dt) + R(i_1 + i_2) \qquad ($$

and $\qquad A\theta = i_2(F + P) + R(i_1 + i_2) \qquad (1$

Solving these for the galvanometer current

$$Wi_1 = e - G(d\theta/dt) - [RA\theta/(F + P + R)] \qquad (1$$

where $\qquad W = T + S + R - [R^2/(F + P + R)] \qquad (1$

Substituting this into the galvanometer equation (1)

$$I\frac{d^2\theta}{dt^2} + \left(\alpha + \frac{G^2}{W}\right) \cdot \frac{d\theta}{dt} + \left[c + \frac{GRA}{W(F+P+R)}\right]\theta = \frac{Ge}{W} \qquad (1$$

In practice, R is much less than $(F + P)$ or $(T + S)$, an the condition for critical damping can be simplified to:

$$\left(\alpha + \frac{G^2}{T + S}\right)^2 = 4I\left[c + \frac{GRA}{(T + S)(F + P)}\right] \qquad (1$$

and the corresponding solution for θ is

$$\theta = \frac{Ge}{Wc'}\left\{1 - \exp\left[-t\sqrt{(c^1/I)}\right] - \sqrt{\left(\frac{c'}{T}\right)} \,.\, t \,.\, \exp\left[-t\sqrt{(c'/I)}\right]\right\} \qquad (1$$

where $\qquad c' = c + GRA/[W(F + P + R)] \qquad (1$

Though the steady state sensitivity has been decreased, th rise time is considerably faster than that achieved

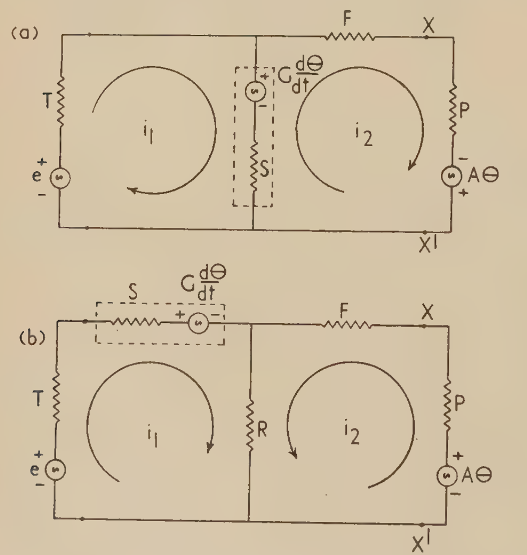
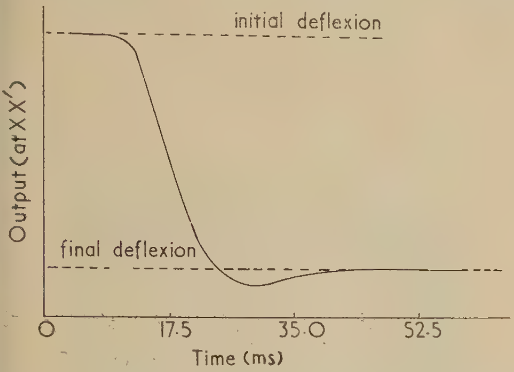


Fig. 3. Schematic circuits of the two basic feedback loops

ıtance variation, as in equation (3). The effect corresponds nechanically increasing the elastic resisting torque c. ypical response curve, obtained with the same galvano- er used previously, is shown in Fig. 4, in which actual es of the circuit resistances are also indicated. The



ig. 4. Galvanometer response curve with proportional feedback

= 0·1 Ω, $S = 11$ Ω, $R = 1$ Ω, $F = 1$ MΩ, $P \simeq 200$ Ω. Output voltage/input voltage = $5{\cdot}9 \times 10^5$.

ıction in gain can also be considered as due to the rease in galvanometer current caused by the feedback easing the input impedance. For the case illustrated in . 4, the input impedance is 110 Ω, compared to a value 1 Ω under similar conditions with no feedback. Increas- the feedback still further correspondingly increases the ut impedance, but has the disadvantage of introducing illatory overshoot as indicated later in Fig. 8 (b).

DIFFERENTIAL FEEDBACK

f feedback is applied to the galvanometer system pro- tional to the differential of the deflexion, it is possible to ieve critical damping without altering the circuit resistance elastic resisting torque. This can be achieved by a circuit

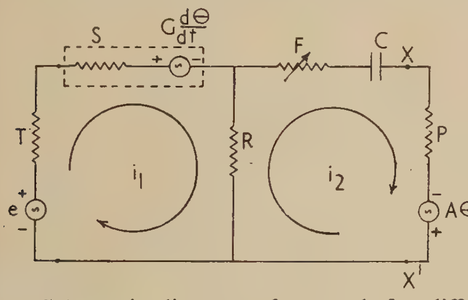


Fig. 5. Schematic diagram of network for differential feedback

the type illustrated in Fig. 5. The currents in the two ps are given by

$$e = i_1(T + S) + (i_1 - i_2)R + G(d\theta/dt) \qquad (17)$$

d

$$A\theta = (P + F)i_2 + (i_1 - i_2)R + \frac{1}{C}\int i_2 dt \qquad (18)$$

ıen the capacitance of C is small, the current i_2 is mainly ided by its impedance, the other contributions to the pedance, F, R, P and i_1 being negligible. Equation (18) ı then be written, upon differentiating both sides, as

$$i_2 = AC(d\theta/dt) \qquad (19)$$

Substituting this into equation (17), to obtain the galvanometer current i_1, and then into equation (1) gives

$$I\frac{d^2\theta}{dt^2} + \left[\alpha - G\left(\frac{ARC - G}{T+S+R}\right)\right]\frac{d\theta}{dt} + c\theta = \frac{Ge}{T+S+R} \qquad (20)$$

and critical damping is obtained when

$$\left[\alpha - G\left(\frac{ARC - G}{T + S + R}\right)\right]^2 = 4Ic \qquad (21)$$

The equation for θ is the same as equation (3), except that R_T is now principally the galvanometer resistance S.

A typical experimental curve obtained under these conditions is given in Fig. 6, together with the resistance and

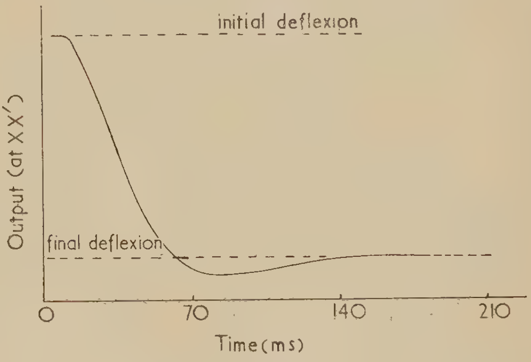


Fig. 6. Galvanometer response curve with differential feedback

$T = 0{\cdot}1$ Ω, $S = 11$ Ω, $R = 1$ Ω, $F = 300$ kΩ, $C = 0{\cdot}003$ μF, $P \simeq 200$ Ω. Output voltage/input voltage = $6{\cdot}75 \times 10^6$.

capacitance values used. The feedback is applied in the opposite sense to the case of proportional feedback considered earlier. The advantage of this circuit is that critical damping can be attained without any loss of sensitivity, compared to the increase in circuit resistance R_T required without feedback.

COMPOUND FEEDBACK

The limitations set to the speed of response using proportional feedback by the onset of oscillatory overshoot can be avoided by using a compound system of proportional and differential feedback. A simple circuit by which this can be

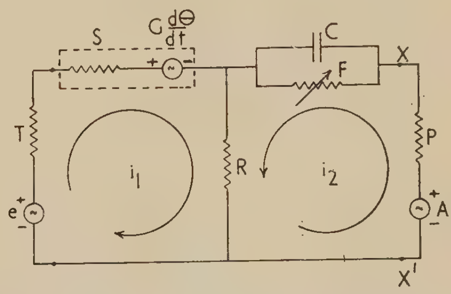


Fig. 7. Schematic diagram of network for compound feedback

achieved is illustrated in Fig. 7. The currents in the two loops are given by:

$$e = (T + S)i_1 + G(d\theta/dt) + R(i_1 + i_2) \qquad (22)$$

and

$$A\theta = (P + R)i_2 + Z \,.\, i_2 - i_1 \,.\, R \qquad (23)$$

where Z is the impedance of the capacitance/resistance combination C/F. When Z is large the other terms can be neglected and equation (23) becomes:

$$A\theta = Zi_2 \tag{24}$$

where $$Z = F/(1 + j\omega CF) \tag{25}$$

Replacing $j\omega$ by d/dt, equation (24) can be written as

$$i_2 = (A\theta/F) + AC(d\theta/dt) \tag{26}$$

Substituting this into equation (22), the galvanometer current i is given by

$$(R+T+S)i_1 = e - (G + ACR)(d\theta/dt) - (RA\theta/F) \tag{27}$$

The overall galvanometer equation can then be written as

$$I\frac{d^2\theta}{dt^2} + \left[\alpha + G\left(\frac{G+ACR}{R+T+S}\right)\right]\frac{d\theta}{dt} + \\ + \left(c + \frac{GRA}{F}\right)\theta = \frac{Ge}{R+T+S} \tag{28}$$

The condition for critical damping and corresponding speed of response can be similarly stated as in equations (14) and (15). These can now be adjusted independently by alteration of the damping and torsion terms, so that any desired speed of response, i.e. c', can be obtained. In the circuit illustrated in Fig. 7, the value of the capacitor C has been chosen to give the required speed of response and the value of the resistance F is varied until critical damping is obtained. A typical curve is shown in Fig. 8(*a*) and Fig. 9 shows a photograph of the oscilloscope trace with 50 c/s time markers. For comparison, the curve Fig. 8(*b*) illustrates the effect of removing the capacitor C; the galvanometer response to a step pulse exhibits a large overshoot with oscillatory decay and it requires a much longer time to reach a steady value. The increased speed of response is obtained at the expense of the sensitivity, the overall gain being reduced by a factor of 180 and the input impedance increased to approximately 4250 Ω.

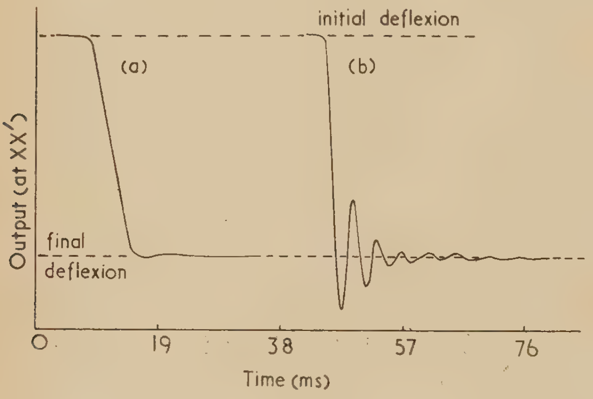


Fig. 8. Galvanometer response curves with compound feedback

Curve (*a*) $T = 1\ \Omega$, $S = 11\ \Omega$, $R = 12\ \Omega$, $F = 300\ \text{k}\Omega$, $C = 0{\cdot}003\ \mu\text{F}$.
Curve (*b*) C omitted.
Output voltage/input voltage $= 2{\cdot}1 \times 10^4$.

SELECTIVE SYSTEMS

There are many applications in which it is desirable that the galvanometer responds to only a limited range of frequencies and has no effective d.c. sensitivity. The following circuits were developed for use with an amplifier operat from an infra-red chopped beam system, details of which is hoped to publish shortly. The sensitivity of the galvan meter to a sinusoidal input at different frequencies can obtained in vector form by replacing the differential fac d/dt in equations (1) and (2) by $j\omega$. The deflexion θ is th

$$\theta = Ge\Big/\left\{R_T\left[(c - \omega^2 I) + j\left(\alpha + \frac{G^2}{R}\right)\omega\right]\right\} \quad (.($$

where $\omega = 2\pi$ (frequency). Under normal operating co ditions the damping term is predominant and the resona term $(c - \omega^2 I)$ is suppressed. The galvanometer can designed, however, by proper choice of the mechanic constants, so that the resonant term is large and the syste is then tuned to a limited range of frequencies.

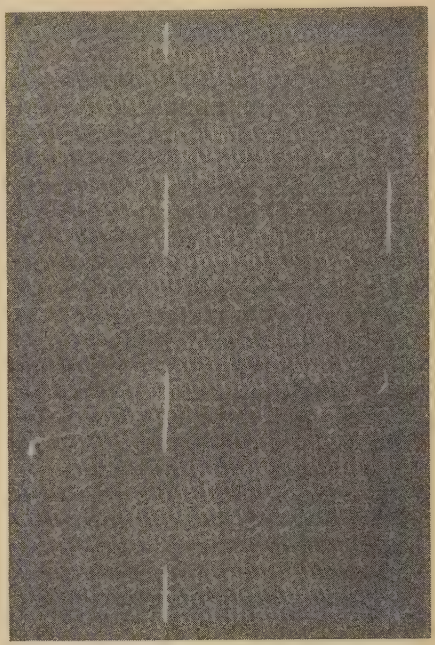


Fig. 9. Trace of a galvanometer response curve with compound feedback recorded photographically using a Cossor type 1049 oscilloscope. The repetition interval between marker traces is 20 ms

Feedback can be used with a standard galvanometer restrict the response to a similar range of frequencies. Th only requirement in this case is that the galvanomet characteristic, as given by equation (29), is reasonably flat up the frequency required. An added advantage of this metho is that frequencies within the range 0–10 c/s can be obtain where normal mechanical tuning becomes difficult.

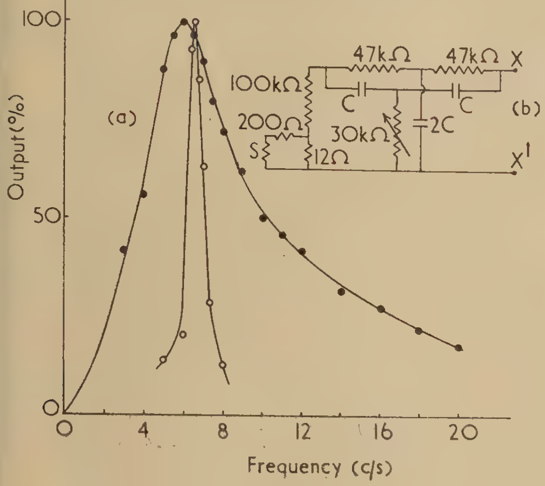
The galvanometer used in this experiment was of th Downing–Hill type as supplied by Messrs. W. G. Pye an Co. Ltd. Feedback was applied to the galvanometer inp through a parallel-T tuned network.$^{(12)}$ At the frequen chosen, 6·75 c/s, the output of the network is zero, but th feedback increases as the frequency departs from this valu A typical response curve is shown in Fig. 10, together wi the parallel-T network. With an overall gain of 5×10^6 resonance, the amplifier closely approached the maximu signal/noise ratio. A similar response can be obtained applying feedback to modify the damping and torsion term but the system is not so stable.

An alternative method of obtaining a resonant syster out feedback, is to connect a capacitor in series with the anometer. If the capacitance is C and the galvanometer stance S, the voltage across the circuit is given by

$$e = Ri + \frac{1}{C}\int idt + G\frac{d\theta}{dt} \qquad (30)$$

y differentiating

$$\frac{de}{dt} = R\cdot\frac{di}{dt} + \frac{i}{C} + G\frac{d^2\theta}{dt^2} \qquad (31)$$



ig. 10. (*a*) Comparative resonance curves for selective edback (open circles) and series-capacitor (closed ircles), systems, maximum gain 5×10^6 and $3{\cdot}75 \times 10^7$ respectively

(*b*) Selective feedback network. $C = 0{\cdot}05\ \mu F$

small values of R, this becomes

$$i = C\left(\frac{de}{dt} - G\frac{d^2\theta}{dt^2}\right) \qquad (32)$$

stituting this into equation (1), and replacing d/dt by $j\omega$,

$$\theta = j\omega CGe\Big/\{[c - (I + G^2C)\omega^2] + j\omega\alpha\} \qquad (33)$$

system is resonant at

$$\omega^2 = c/(I + G^2C) \qquad (34)$$

ere

$$e = (\alpha/GC)\theta_r \qquad (35)$$

By altering the value of C, the resonance frequency can be adjusted to a given value. The deflexion θ_r at resonance is proportional to the capacitance. The highest frequency to which the system can be tuned is obtained when C is small and is given by c/I; decreasing C beyond this limit only reduces the deflexion θ_r. The lower limit is set by the relative magnitude of the resistive and capacitative terms in equation (30). When C becomes very large the resistive term can no longer be neglected and damping is introduced, reducing the selectivity. Typical values of these limits obtained with the Pye galvanometer ($S = 48\ \Omega$) are 5 and 17 c/s, with capacitor values 50 and 1 μF respectively. With the Downing galvanometer ($S = 11\ \Omega$), a range of 6 to 90 c/s could be obtained with capacitor values from 1000 to 0·1 μF. A resonance curve, obtained with this latter galvanometer, is shown in Fig. 10 for comparison with the feedback system. The main disadvantage of the capacitor method is the large values of capacitance required, but both systems have been successfully applied to adapt a galvanometer amplifier with its relative simplicity to infra-red recording using fast thermopiles.

More complex systems of feedback, utilizing double differentiation circuits and compound systems of these with the methods already discussed, can also be used. In general, however, there is not sufficient improvement to justify the extra complication.

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Interferometer based on four diffraction gratings

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An interferometer based on diffraction gratings, used over their whole area, and designed to overcome some of the disadvantages of the four-mirror Mach–Zehnder arrangement is described. Its theoretical and practical assessment leads to the conclusion that, in comparison with the latter, it is remarkably inexpensive and insensitive to misalinement, though wasteful of light and subject to certain residual optical imperfections.

the course of research into the mechanism of ignition of mixtures by heated surfaces, an interferometer was uired which would give a continuous record of gaseous ractive index changes (as a measure of the progress of ction and the release and transfer of heat) in the vicinity a hot body.

The requirements of such an instrument, common to much combustion work, are: (*a*) adequate separation of the hot test space from optical components and from the reference path; (*b*) the use of a single traverse by a light beam fully parallel (i.e. not from a slit collimator); (*c*) the ability to produce, by introduction of a lens, an interferogram in a plane optically conjugate with the test space, in order that any rays deflected by refractive index gradients should terminate on the corresponding points of the image; and (*d*) an adequate field of view area.

The instrument commonly used for such purposes is the four-mirror Mach–Zehnder interferometer, which satisfies the above criteria but suffers from certain disadvantages. The two most serious are its great sensitivity to misalinement and its high cost. The former necessitates inclusion of elaborate mechanical devices linking the mirrors and/or the use of lengthy alining procedures. The latter is due to the large area of optical flats required and the precision and rigidity demanded of their mounting and linking mechanism.

The interferometer here described was developed in order to overcome these limitations whilst adequately fulfilling the initial requirements.

THE INTERFEROMETER

The optical elements used here to split and recombine the parallel light beam are four diffraction gratings situated at the corners of a parallelogram and orientated with their planes perpendicular to the incident beam direction. (The principle of using a grating to split a beam for interferometric purposes has previously been proposed$^{(1)}$ and tested$^{(2)}$ in a system in which incident light was brought to a point focus on the ruled surface.) In the present system, the wave-front is divided across the whole grating area, and several convenient arrangements for the disposition of the gratings suggest themselves. Two of the simplest are illustrated in Fig. 1(*a*) and (*b*).

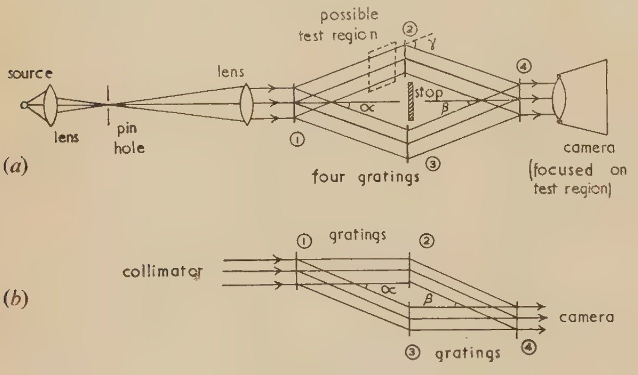

Fig. 1. Suitable dispositions of gratings

The parallel monochromatic beam from the collimator is split by the first grating, producing a series of diffracted beams in directions given by

$$g \sin \theta_n = n\lambda \tag{1}$$

where λ is wavelength, g the rule spacing, and θ_n the angle of diffraction in the nth order. In arrangement 1(*a*) the two first orders are chosen for the interferometer beams, the zero order being blocked off, whilst in Fig. 1(*b*) the zero and first order of grating (1) are employed.

Thus

$$\alpha = \sin^{-1} (\lambda/g) \tag{2}$$

Gratings (2) and (3) are then mounted parallel to grating (1) in the positions shown so that they intercept the two beams and, by further diffraction, converge them on grating (4), utilizing the second orders in arrangement 1(*a*) and first orders in arrangement 1(*b*). Recombination at grating (4) takes place in its several orders. The order difference between beams becoming parallel in arrangements 1(*a*) and 1(*b*) is two and one respectively. The camera is then placed in that emerging beam (see below) designed for maximum intens and visibility.

Gratings (2) and (3) may be rigidly mounted in a flat pl and regarded as two parts of a single grating. It is, in a case, desirable to use as support for the rulings adjac sections cut from a single glass plate in order to minim differences in optical thickness in these two gratings. T test space may be chosen in any one of the four arms, a point giving the largest distance from the adjacent pa consistent with adequate separation from the nearest grati In this manner, the size and separation requirements o particular type of test object dictate the choice of lin dimensions and rule spacing (which determines angles). T grating area is also involved by limiting the maximum fi of view available.

The form of the ruling profile is chosen such as to g maximum intensity in the orders utilized in the particu geometric arrangement. Where the ruling form introdu asymmetry (i.e. intensity differences between equal orders opposite sides of zero order) the complementary grating m be used in such a sense as to compensate and maintain t ultimate intensity of the two beams equal, for maximu fringe visibility.

It is seen that in the absence of a test object and barri optical imperfections in its elements, the interferometer normal adjustment produces a constant-order fringe coveri the whole field of view.

THEORETICAL ASSESSMENT

It may appear at first sight that any advantages this syste offers over that of Mach and Zehnder are marginal, for t following reason. Between separation and recombinati the two beams traverse a grating each (the end gratings and 4 being oriented with their glass supports outwar Differential optical imperfections in these gratings and th supports are therefore featured on the interferogram a their complete elimination would require gratings, t quality and cost of which would be comparable to Mach Zehnder mirrors. This argument, however, misses the ma purpose of the grating interferometer.

Any malorientation or optical imperfection which resul in the inclination of one emerging wave-front to the oth gives rise to fringes of spacing determined by the size of th angle of inclination. This is true of parts of the wave-fron and of the wave-front as a whole. The effects of a loc imperfection are to produce some localized fringes which a a constant property of the apparatus and, once known fro a "blank," can be subtracted from the effects measure This would be permissible in most combustion applicatio but is, of course, conditional upon the production of legible field of fringes, i.e. on the inclination of the who wave-fronts being confined to within certain limits.

In the Mach–Zehnder interferometer, the ultimate ang between wave-fronts is the difference between twice the su of the angular errors in mirror alinement within each pat These angles are to be measured on the scale of units (wavelength/field of view dimensions)—corresponding to on fringe per field. Thus a criterion of an absolute maximu of, say, ten fringes/cm confines the permissible sum angular errors in mirror setting to about 3×10^{-4} ra (yellow-orange light).

It follows that the setting of the mirrors on the Mach Zehnder interferometer requires very high precision befo any useful fringes are obtainable at all, and there woul seem little point (even financially) in using inferior optic surfaces in the type of mounting required.

he case of a grating is rather different. The equation erning the ray path through it may be written

$$g(\sin i \pm \sin r) = n\lambda \qquad (3)$$

d r being the angles of incidence and diffraction in the order respectively in the plane perpendicular to the rulings. ifferentiation for a constant order gives, numerically,

$$di \cos i = dr \cos r \qquad (4)$$

isider a small angular malorientation in the principal ion $\delta\phi$ of the grating.

hen

$$di = \delta\phi \quad \text{and} \quad dr = \delta\phi(\cos i/\cos r) \qquad (5)$$

i were equal to dr there would be no effect of grating tion on ray direction, and the change in direction of the $\delta\theta$, due to $\delta\phi$, would be zero. In general

$$\delta\theta = dr - di = \delta\phi[(\cos i/\cos r) - 1] \qquad (6)$$

is, providing i and r are relatively small, to the first roximation (cosines approximately equal to unity), $\delta\theta = 0$. next approximation gives

$$\simeq \delta\phi\left[\frac{1-(i^2/2)}{1-(r^2/2)} - 1\right] \simeq \frac{\delta\phi}{2}(r^2 - i^2) = \frac{\delta\phi}{2}(r-i)(r+i) \qquad (7)$$

ection of Fig. 1(*a*) and (*b*) shows that for all the gratings ployed either: (*a*) $i = r$, which by equation (7) gives $= 0$; or (*b*) one of the angles is zero, the other corre- nding to the first order of the grating considered or of immediately preceding it. For $i = 0$ and r (first order) nall angle, equation (3) gives

$$r \simeq \lambda/g$$

stitution into equation (7) gives, numerically,

$$\delta\theta \simeq \delta\phi(\lambda^2/2g^2) \qquad (8)$$

ummarizing, the error in the angle of the beam introduced an error in the angle of the grating is, to a first approxi- ion, zero. The second approximation gives zero error some of the gratings, and for others (the worst case) an or proportional to the grating malorientation, but greatly inished by the factor $\frac{1}{2}$ (wavelength/rule spacing)^2. This o be compared with the factor of two applicable in the of mirrors. It will be seen that the worst case, even for tings as fine as 7500 lines/in., shows still only about 00th of the sensitivity to malorientation of mirrors in the ch–Zehnder system.

fundamental disadvantage of the grating interferometer compared with the Mach–Zehnder instrument is its con- rable wastage of light intensity. If f_b^a denotes the fraction intensity transmitted by the a^{th} grating in the b^{th} order ler its conditions of use, arrangements [1(*a*)] and [1(*b*)] final fractions of, respectively,

$$2f_1^1 f_2^2 f_1^4 \quad \text{and} \quad 2f_0^1 f_1^2 f_1^4 \qquad (9)$$

f these, the latter is usually greater than the former, ough the full expression is a complicated function of the ove profiles. An obvious way of improving light utiliza- n is to select gratings with groove profiles such as to centrate the diffracted light into the required orders. tings may be constructed with ruling profiles designed concentrate intensity in any required order or orders,(3) unless gratings which are commercially available are cted, the cost of producing an unorthodox ruling would prohibitive.

Another possible approach is the focusing of the camera on the last grating. This collects on the image all the duplicated orders from that grating incident on the lens. The theoretical maximum improvement for an infinite lens aperture on expressions (9) thus consists of removal of the last factor. This procedure, however, would destroy the desirable facility of focusing the camera on the test region. In any case, the loss always exceeds considerably the theoretical 50% of the Mach–Zehnder.

Even a purely theoretical assessment thus indicates that the grating interferometer is not a simple alternative to the Mach–Zehnder in all cases. In the form proposed it is inexpensive and very easy to set up and adjust. No elaborate precautions are necessary to produce a legible interferogram, but the removal of residual fringes would presumably involve quite a disproportionate increase in cost (though not in sensitivity to malorientation). The authors are not aware of commercially available gratings having optical properties approaching those usually demanded of Mach–Zehnder mirrors. Furthermore, the grating interferometer is of little value in cases where light intensity is a limiting factor.

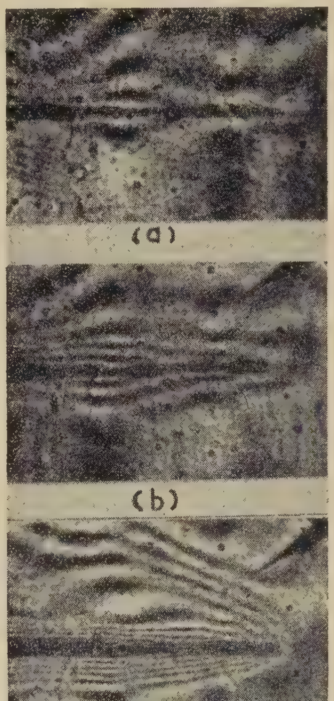

Fig. 2. Interferograms portraying development of temperature distribution in vicinity of radiation-heated plate

PRACTICAL ASSESSMENT

For the prototype interferometer constructed, four gratings of 7500 lines/in. rulings were supplied by the National Physical Laboratory, two giving a first-order maximum (N.P.L. Ref. No. P949) and two a second-order maximum (N.P.L. Ref. No. P968). Photometric measurements of their transmission intensities in various orders were carried out by using a constant area photocell in a parallel beam. These showed that, for the P949 type, the two first orders contained approximately 40% and 15% of the incident light intensity, and that the P968 type concentrated about 30% into one second order. The gratings were all resin replicas of ruled area 3 × $2\frac{3}{4}$ in.

Using mercury green light derived from a high-pressure mercury arc and Kodak Wratten 58 filter, angles α and β in Figs. 1(*a*) and (*b*) were equal, about $8\frac{1}{2}$°—and angle γ in Fig. 1(*a*) was therefore about 17°. The P949 type gratings were for use in positions (1) and (4) and the P968 type in positions (2) and (3), the resin replicas for the latter pair having been mounted on adjacent sections cut from selected 3 mm plate glass, to ensure reasonably uniform and equivalent optical thickness in the two beams. The gratings were all mounted on supports; (1) and (4) individually and (2) and (3) sharing a support. These were then clamped to an optical bench so as to give the required disposition of the gratings. The mounts were constructed to provide independent screw adjustment of rotation of each grating in its own plane.

The other position variables were rotation of the clamp about a vertical axis and translation along the optical bench.

In accordance with theory, it was found that this rather crude bench mounting, together with a simple and obvious adjusting procedure, sufficed to produce fringes. Their number could then be decreased and their width increased by further small adjustments approaching the condition of a constant-order fringe. This condition, however, could not be fully attained and a few residual fringes, due to optical imperfections, always remained. (This did not impair the legibility of the interferogram appreciably.)

In the absence of steep refractive index gradients in the test section no camera lens was used, thus giving fringes, superimposed on a simple shadow-graph of the test object, which were visible on a ground glass screen. In combusti applications, however, the use of a lens focusing the t region on the screen or photographic plate is recommen for reasons discussed at the beginning of the paper.

Fig. 2 shows a sequence of interferograms portraying development of a temperature-induced refractive in profile in air. The distribution occurs in the vicinity o horizontal radiation-heated plate and is recorded at vari times during the initial period of temperature rise. T interferometric arrangement shown in Fig. 1(*a*) was used

CONCLUSIONS

An interferometer based on diffraction gratings has be designed, examined theoretically and a prototype tested practice. It has been shown to compare favourably w some, but not all, features of the Mach–Zehnder interfe meter. In particular it is inexpensive, easy to adjust a insensitive to small errors in adjustment. Its residual opti imperfections, however, though in themselves no seri obstacle in many applications, cannot be eliminated witho considerable increase in its cost. It is, moreover, wasteful light intensity. It appears well suited to many applicati in combustion and allied research.

ACKNOWLEDGEMENTS

It is a pleasure to thank Prof. D. M. Newitt and Dr. J. Burgoyne for their interest in and encouragement throug the investigation of which this work forms part. We a wish to thank Dr. L. A. Sayce of the National Phy Laboratory in connexion with the selection and product of suitable gratings, and the Gas Council to whom one us (N. B. W.) is indebted for financial support.

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High-resolution nuclear resonance apparatus

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[*Paper received* 28 *October*, 1958]

A nuclear resonance spectrometer for observing high-resolution spectra of hydrogen and fluorine resonances is described. The spectrometer is of extremely simple design but its stability and resolving power is approximately 1 in 10^8 when using samples of diameter approximately 5 mm. A thermally-lagged permanent magnet is used to provide the main magnetic field and a simple bridged-T spectrometer is used.

A number of sophisticated high-resolution nuclear resonance spectrometers have been described using electromagnets$^{(1, 2, 3)}$ and permanent magnets.$^{(4, 5, 6)}$ The instrument described below represents an attempt to construct a very simple spectrometer without serious loss of performance. The apparatus comprises a permanent magnet to provide the stable and homogeneous magnetic field, and the measuring and recording equipment.

THE MAGNET

For high-resolution spectroscopy it is desirable to provi a polarizing field H_0 which is as high as possible, and uniform and stable as possible. The highest magnetic fie can be achieved with electromagnets, but very sophisticat devices are required to stabilize the field of an electromag sufficiently. In the interests of simplicity and cheapness was therefore decided to use a permanent magnet of fie gth about 7000 G. This magnet was constructed by lard Ltd., and is described in detail elsewhere.(7)

ne magnet is of conventional design with a square yoke enerous dimensions to minimize the effects of external netic disturbances. Provision is made for adjusting the netry of the 8 × 1½ in. gap after the magnet has been netized. The magnet is supported 18 in. from the floor the plane of the yoke horizontal and the gap vertical. thermally insulated with a 2 in. layer of Jablite expanded styrene, and an aluminium case surrounds the whole mbly. A vigorous stream of air is forced over both s of the magnet from the space beneath it, and the perature of this air is regulated at 27° C to a few hundredths degree with a platinum resistance thermometer and an bridge thermostat. Access to the gap is provided through uare hole in the top of the box. Fitted to each pole face printed circuit set of electrical shims, designed by Dr. Golay.(8) These shims provide a very quick and accurate nod of making final adjustments to the homogeneity of magnet; the adjustments are only slightly interdependent none of them changes the mean value of the magnetic significantly. With this spectrometer, only four of the een sets of coils are used.

THE SPECTROMETER

twin-T bridge method of detection is used,(9) and the n components of the apparatus are shown in the block ram of Fig. 1.*

he radio-frequency generator. A G.T. cut quartz crystal Standard Telephones and Cables Ltd.) is used, oscillating 00 kc/s. This crystal is in an oven at a temperature lated to a few hundredths of a degree Centigrade. The kc/s signal is used to operate a frequency synthesizer t in this laboratory by Mr. D. Cooke and Mr. A. McLeod ch provides any output frequency between 25 and Mc/s at intervals of 40 kc/s. The final output passes through an attenuator to give any voltage at 75 Ω impedence between 100 mV and 5 μV.

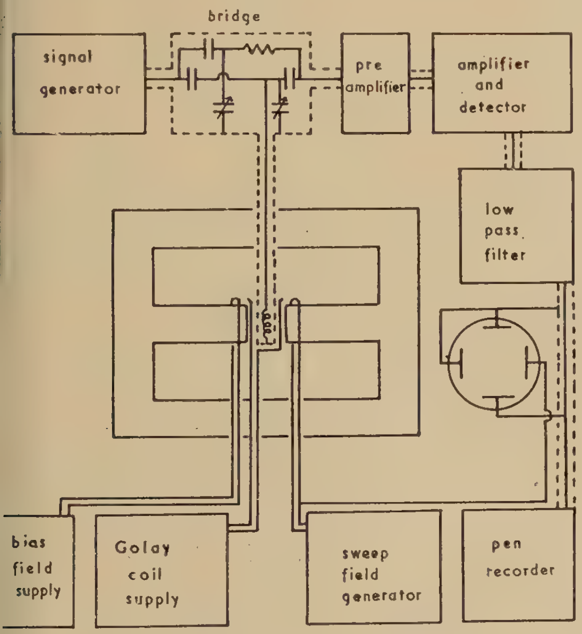
bridge
signal generator
pre amplifier
amplifier and detector
low pass filter
bias field supply
Golay coil supply
sweep field generator
pen recorder

Fig. 1. Block diagram of apparatus

The 100 kc/s signal from the G.T. cut quartz crystal oscillator is used to lock multivibrator harmonic generators running at 200 kc/s. The 200 kc/s signal is multiplied to 1 Mc/s and divided to 40 kc/s. These signals are filtered and used to lock further harmonic generators. The appropriate harmonics are mixed and filtered and selected to give the final output according to the scheme shown in the block diagram in Fig. 2. The intensity of signals 40 kc/s on either side of the selected frequency is approximately 45 db down on the main one. Automatic gain control is applied to the final stages of the output filters with a high gain loop and with a time constant of about 0·1 s. This ensures that the output level is held very closely constant and also reduces the intensity of low-frequency noise.

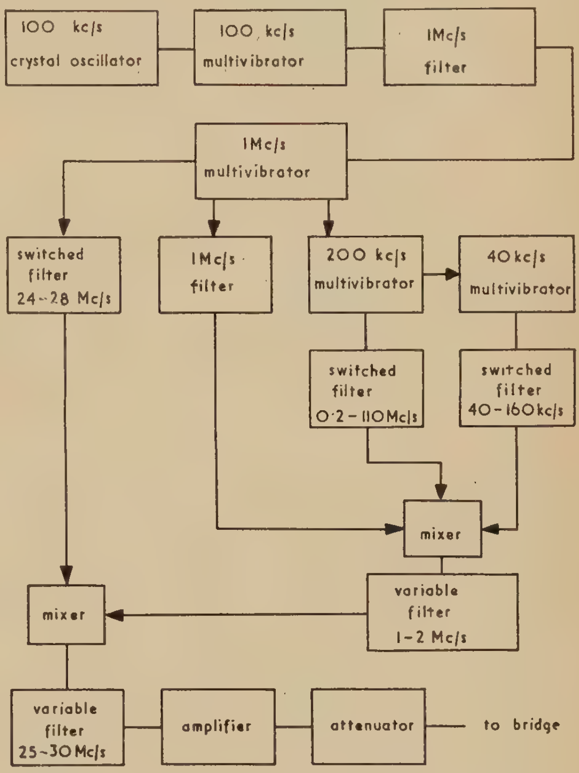
100 kc/s crystal oscillator
100 kc/s multivibrator
1Mc/s filter
1Mc/s multivibrator
switched filter 24–28 Mc/s
1Mc/s filter
200 kc/s multivibrator
40 kc/s multivibrator
switched filter 0·2–110 Mc/s
switched filter 40–160 kc/s
mixer
variable filter 1–2 Mc/s
mixer
variable filter 25–30 Mc/s
amplifier
attenuator
to bridge

Fig. 2. Block diagram of frequency synthesizer

The bridge. The components of the bridge are contained in a cubical copper box which is set into the top of the magnet case with its two adjustments in the top. The bridge is extremely easy to adjust and rarely shows any drift except at very high radio-frequency levels.

The probe. The probe is shown in Fig. 3. The single radio-frequency coil *A* is wound on a 6 mm diameter thin-walled glass sleeve, and the leads are brought upwards to a short coaxial cable connected to the bridge. The coil former is supported at each end. The aluminium ends *BB'* of the probe contain inset Teflon bearings *CC'*, of diameter about 4·5 mm. An aluminium outer tube *D* supports the end pieces, as well as screening the coil and keeping it free from contamination. The sample tubes are made of thin-walled glass of outside diameter 4·5 mm, about 12 cm long. Either a plastic turbine or a cork *E* can be slipped over the sample tube, which is then dropped into the central sleeve. Air

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The authors will supply, on loan, detailed circuit diagrams of apparatus to any interested readers.

jets F spin the sample tube.(10) in the probe, and the air for this is first brought to thermal equilibrium with the magnet. The probe is mounted permanently with the coil at the centre of the Golay shims, and no adjustment in the gap is needed except when changing to a different probe. The position is, in fact, not critical to within ¼ in. in any direction.

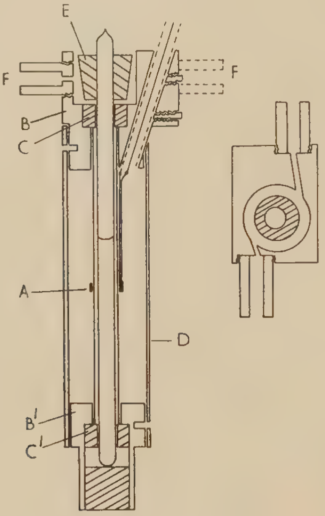


Fig. 3. Sample holder

The radio-frequency amplifier. A cascode pre-amplifier(11) is followed by four stages of gain at the operating frequency of 29·9200 Mc/s, followed by a diode detector. The overall voltage gain is about 10^5. The amplifier is driven from stabilized low tension and high tension supplies and is left on permanently. The amplifier can be tuned with slugs in the tuning coils, and it is a simple matter to retune it to the fluorine resonance frequency of 28·1600 Mc/s in this magnet.

Recording. The d.c. output from the detector passes through an *RC* network to limit the bandwidth, and the standing out-of-balance voltage is backed-off with a small dry cell. The signal voltage is then applied to a d.c. oscilloscope or to a Sunvic potentiometric recorder.

Magnetic field scan. The spectrometer is scanned by varying the magnetic field with the aid of coils wound on the tips of the pole pieces. The current is provided from an electronic linear time base with switched controls. Scan times can be varied from 0·1 s to 45 min, and the range of scan from 5 mG to 5 G. The precise points at which the scan starts and stops can be preset, and will remain constant to a few cycles per second over a period of several hours.

Calibration. The conventional side-band method employed,(12) in which a weak audio-frequency modula is applied to the magnetic field. At given settings of sweep generator, the calibration remains remarkably const For example, over a period of one month the calibra remained within a range of ±1%.

PERFORMANCE

Resolving power. The resolving power is approxima 1 in 10^8. The line widths obtained are illustrated by recordings of the resonance of the hydrogen atom of aldehyde group of acetaldehyde (Fig. 4) of which the f peaks are 2·85 c/s apart, and by the recording of the hydro resonance of the 4-position of furfural (Fig. 5), for wh the lines are 1·4 c/s apart. The recording of the spectrum acidified ethyl alcohol (Fig. 6) shows the resolving pow normally attainable; this spectrum was obtained more th twenty-four hours after any adjustment to the field shi had been made.

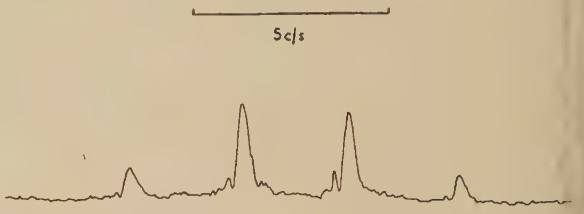


Fig. 4. CHO resonance of acetaldehyde. Sweep rat 1·75 mG/min

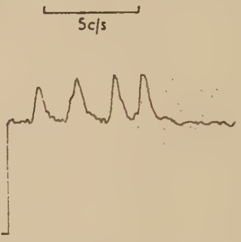


Fig. 5. 4–H resonance of furfural. Sweep rate 3·5 mG/min

Stability. The field stability depends on magnet tempe ture and external disturbances. The temperature control such that the magnet drifts slightly from day to day, but drift is not serious for shift measurements to a few cyc per second. The low drift is illustrated by the equal spac

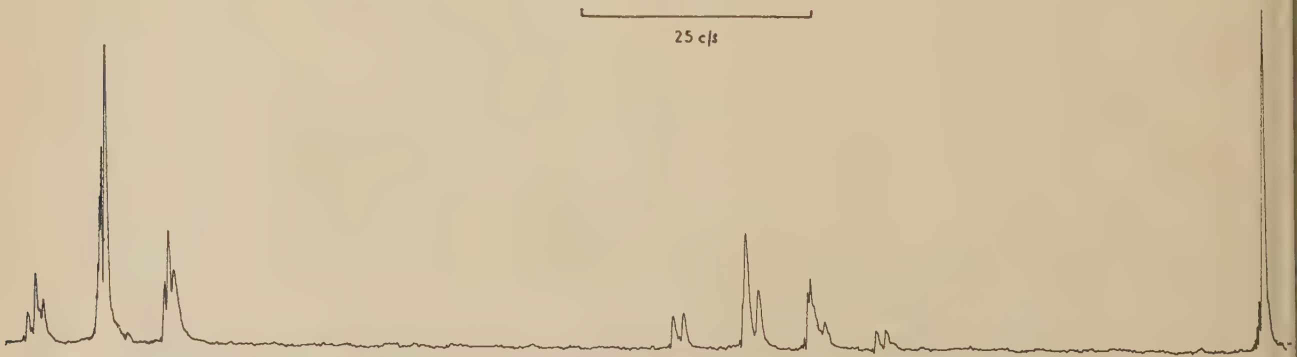
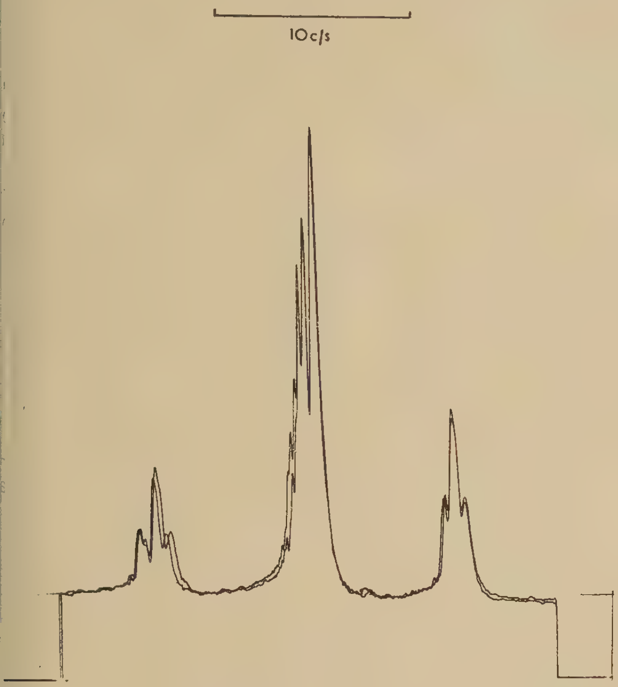


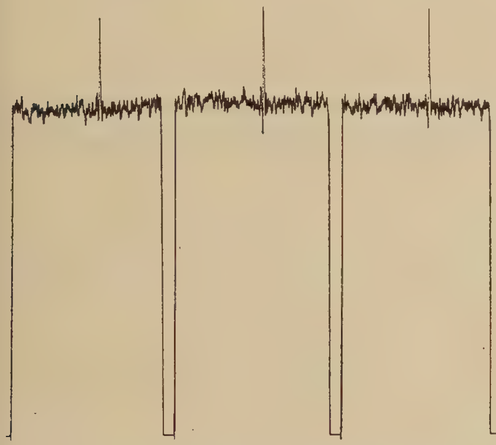
Fig. 6. Spectrum of acidified ethyl alcohol. No adjustment of field homogeneity since the day before. Sweep rate 2·25 mG/min

e acetaldehyde lines (Fig. 4), and by Fig. 7, which shows recordings of the methyl resonance of ethyl alcohol on same trace.

he day-to-day drift of the magnetic field during the past months has been within the range ±50 c/s. The low stray field of the magnet at bench level means that the field is very insensitive to the movement of iron objects on the benches of the laboratory which are only a few feet away. Movement of gas cylinders or of iron objects at floor level near the magnet cause significant displacements of the field, and are usually avoided when the apparatus is being used.



ig. 7. Double recording of CH_3 resonance of ethyl alcohol. Sweep rate 3·5 mG/min



ig. 8. 0·1 molar chloroform in carbon tetrachloride. Sweep rate about 50 mG/min

Sensitivity. Fig. 8 shows a recording of the hydrogen resonance of a solution of chloroform in carbon tetrachloride containing 0·1 g atoms of hydrogen per litre. The sensitivity could probably be improved by the use of a more sophisticated radio-frequency amplifier.

The spectrometer has a stability and resolving power of the highest quality but its simple design has obvious advantages. The instrument has been in regular use for over a year in this laboratory.

ACKNOWLEDGEMENTS

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Illuminant for the colorimetry of fluorescent materials

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The colorimetry of specimens containing fluorescent whitening agents (optical bleaches) requires an illuminant with adequate ultra-violet content to at least 3600 Å. Single sources based on the filament lamp have, generally, a low ultra-violet content. The use of two sources, one equivalent to Illuminant C provided by a filament lamp screened with an O.B. 8 filter, and the second the same lamp screened with an O.X. 1 or modified O.X. 1 ultra-violet filter, is suggested as giving a satisfactory approximation to the daylight spectral distribution, both in the visible and in the ultra-violet regions.

The widespread and increasing use of fluorescent whitening agents (optical bleaches) for fabrics and paper has made important the provision of suitable illuminants, both for visual colour matching and for instrument colorimetry. The International Commission on Illumination at the Zurich meeting of 1955⁽¹⁾ gave attention to this problem and recommended that the suitability of light sources for the measurement of fluorescent materials be further considered, mentioning the Xenon high-pressure lamp and also Illuminant C, supplemented by other sources, as examples for consideration.

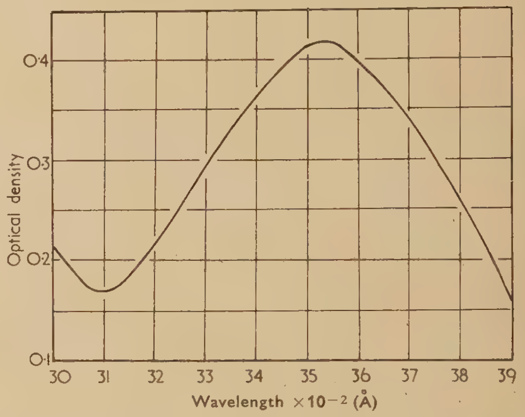
An illuminant for the measurement of fluorescent materials should have a spectral distribution approximating to that of natural daylight with its accompanying ultra-violet radiation. Middleton⁽²⁾ has given data on the spectral distribution of radiation from an overcast sky and these will be taken in this paper as indicating the order of spectral distribution required from an artificial source. (It should be noted that daylight can vary widely in its ultra-violet content—see, for example, data supplied by Luckiesh.⁽³⁾)

EXCITATION OF OPTICAL BLEACHES

Fig. 1 shows a typical absorption curve for a solution of optical bleach. The high absorption between 3400 Å and 3700 Å indicates that high excitation takes place over this range. An artificial-daylight source should therefore have an adequate ultra-violet content at least down to 3600 Å, and preferably down to 3400 Å.

ILLUMINANT C

This standard source, obtained by means of a filame lamp operating at a colour temperature of 2854° K a screened by a specified liquid filter, matches daylight ve well in the visible range but is inadequate in its ultra-viol content. At 3600 Å, the intensity of Illuminant C is on about one-quarter of that of the comparable daylight, a



Typical absorption of long-wave ultra-violet light by a solution of optical bleach (Tinopal T.A.) 0·001 % in 50 % ethanol, 1 cm thickness

Table 1. *Ultra-violet spectral distribution of illuminants*

Wavelength (Å)	*Relative energy*						
	*Daylight**		*Illuminant C†*		*Supplemented Illuminant C†*		*Xenon§ lamp*
	Middleton	*Luckiesh*	*Liquid filter*	*O.B. 8 filter*	*with O.X. 1‡*	*with O.X. 1/O.B. 10*	
3000	2·3	0·8	—	—	—	—	25
3100	14·2	7·5	—	—	1·0	—	23
3200	37·6	19·7	0·01	0·4	5·0	0·5	30
3300	52·5	32·1	0·4	1·0	11·6	1·7	30
3400	50·4	36·6	2·7	3·2	21	6	44
3500	56·0	39·4	7·0	10·8	36	18	57
3600	56·0	44·2	12·9	22·7	55	37	65
3700	64·7	51·2	21·4	35·0	77	59	73
3800	60·0	52·0	33·0	48·5	92	77	87
3900	57·6	57·6	47·4	65·8	84	78	99
4000	76·5	68·0	63·3	81·5	86	84	93
4100	95·6	86·0	80·6	96·5	98	97	87
4200	96·0	94·4	98·1	101	101	101	84
5600	105·3	105·3	105·3	105·3	105·3	105·3	105·3
6500	96·5	87·3	88·2	74	74	74	108
7000		86·1	76·3	138	243	148	

* Derived from the data of Middleton⁽²⁾ and Luckiesh⁽³⁾ respectively.
† Lamp colour temperature = 2854° K.
‡ O.X. 1, 2 mm thick.
§ Approximate data derived from Siemens block diagram.⁽⁴⁾

400 Å it is only about one-twentieth, as may be seen from le 1.

n improvement is achieved if glass filter, type O.B. 8 (by nce Brothers Ltd.), is substituted for the liquid filter. n, at 3600 Å the intensity is 40% of the daylight value, at 3400 Å it is only about 6%. The values in Table 1 e obtained with a filter thickness of 3·2 mm. Different ches of O.B. 8 are subject to tolerance differences, but e are slight and do not affect the point that the glass r is superior to the liquid filter in the ultra-violet region.

SUPPLEMENTED ILLUMINANT C

much better approximation to the required ultra-violet ctral distribution can be obtained by the use of two minants, one of them the equivalent of Illuminant C but 1 an O.B. 8 filter as mentioned above, and the other a plementary illuminant employing the same lamp but ened with a "black glass" filter, such as the Chance filter, O.X. 1. A practical arrangement is to employ inter- ngeable filters over the same lamp and take the readings secutively.

he readings are added together and the sum gives the ct of an illuminant having the spectral distribution given Table 1 (Col. 6). It will be seen that the intensity at 0 Å is similar to the daylight value. At 3400 Å the inten- is about 40% of the daylight value, whilst at 3800 Å it bout 150%. These deviations from the daylight values 400 Å and 3800 Å are not unduly great for an artificial light, bearing in mind that daylight itself can vary widely also that the daylight values at 3400 Å will be reduced oors because of absorption by the window glass (typical smissions of window glass are 70% at 3400 Å and 20% 200 Å).

SUPPLEMENTARY FILTER WITH LOW TRANSMISSION IN THE RED REGION

he normal "black glass" filters, including the O.X. 1, smit in the deep red region beyond 6800 Å; data on the X. 1 show a transmission of about 7% at 7000 Å. This s not preclude the use of the O.X. 1 alone as a supple- ntary filter in the measurement of optical bleaches, and probably the only inconvenience from the presence of stray red light would be when red fluorescent light was to be measured, or when visual examination of the fluorescent sample was also to be made. Data for 6500 Å and 7000 Å are included in Table 1. (It should be appreciated that the radiation at 7000 Å has little effect on the chromaticity.)

ole 2. *Ultra-violet spectral distribution (illuminant based on lamp at 3000° K)*

velength (Å)	*Relative energy*		
	With O.B. 8 filter alone*	*With O.B. 8 filter supplemented with O.X. 1*	*With O.B. 8 filter supplemented with O.X. 1/O.B. 10*
3100	—	1·3	—
3200	0·7	7·5	0·8
3300	1·6	14·5	2·5
3400	4·5	26	7·7
3500	13·9	44	22·4
3600	27·5	67	45
3700	40	88	67
3800	55	101	84
3900	72	91	85
4000	89	92	91
4100	102	103	103
4200	106	106	106
5600	105·3	105·3	105·3
6500	73	73	73
7000	128	212	136

* Chromaticity equivalent to Illuminant C.

A composite filter with very low red transmission (about one-tenth of that for O.X. 1) is obtained by combining the O.X. 1 filter (2 mm thick) with a thin layer of the Chance filter, type O.B. 10 (0·8 mm thick). Unfortunately, the ultra-violet content is also appreciably absorbed, as can be seen from Table 1 (Col. 7). However, the ultra-violet content can, to some extent, be increased by employing a lamp at a higher colour temperature than 2854° K, and 3000° K is a practicable colour temperature, as will be shown in the next section. Table 2 gives the energy distribution obtained with a lamp at 3000° K in conjunction with an O.B. 8 (3·0 mm) filter to give a chromaticity similar to Illuminant C, and also the distribution when this source is supplemented firstly by the ultra-violet light transmitted through an O.X. 1 (2 mm) filter, and alternatively by the ultra-violet light transmitted through the O.X. 1/O.B. 10 filter previously described.

EXAMPLE OF MEASUREMENT OF PAPER CONTAINING OPTICAL BLEACH

The last mentioned illuminant—namely a lamp at 3000° K with an O.B. 8 filter giving Illuminant C chromaticity, supplemented by the ultra-violet light through an O.X. 1/O.B. 10 filter—is employed in a commercial colorimeter (the author's fluorescence measuring unit) designed for the measurement of fabrics and paper containing optical bleach. The lamp is a 12 V 100 W projector lamp which, at 12 V, runs at a colour temperature of approximately 3100° K and has a life of 50 hours. In the instrument, it is slightly underrun to give 3000° K, and the life is 150 hours.

Table 3. *Chromaticity of white paper containing optical bleach*

Illumination	*C.I.E. chromaticity co-ordinates* *x*	*y*	*z*
O.B. 8 filter plus u.v. absorbing filter	0·312	0·322	0·366
O.B. 8 filter only	0·308	0·314	0·378
O.B. 8 filter and supplementary O.X. 1/O.B. 10 filter	0·301	0·307	0·392
Daylight (overcast sky)	0·303	0·310	0·387

The measurements of chromaticity given in Table 3 were made on a sample of white paper containing a high amount of optical bleach, probably almost the maximum which would be applied to paper. The measurements included one in which all incident ultra-violet light was excluded by an ultra-violet absorbing filter placed over the O.B. 8 filter, and also another measurement in which daylight from an overcast sky was allowed to enter the colorimeter as the illuminant. A visual examination of the samply in daylight showed it to be appreciably more blue than a magnesium carbonate block.

DATA ON LAMPS AND FILTERS

The data on standard Illuminant C and the lamps at 2854° K and 3000° K have been obtained from the published C.I.E. and Planckian radiator data. The transmissions for the filter glasses O.X. 1 and O.B. 10 have been obtained from typical data provided by Messrs. Chance Brothers Ltd. and the data for the O.B. 8 are from an actual spectrophotometric curve, which was found to be in good agreement with the Chance data.

Typical data for the xenon lamp are included, for comparison, in Table 1.(4)

CONCLUSION

In assessing an illuminant for the excitation of optical bleaches, the value of relative energy at 3600 Å is a suitable criterion. It is shown that a single source with an improved ultra-violet content over the liquid filter C.I.E. Illuminant C can be obtained by the use of an O.B. 8 glass filter and a lamp at a colour temperature of 3000° K. Then the energy at 3600 Å can reach 50% of the daylight value.

With the addition of supplementary ultra-violet light provided by a lamp with an ultra-violet filter, the daylight value at 3600 Å can be achieved. A suitable supplemented source is a lamp at 2854° K screened with an O.B. 8 fil as the main source, and screened with an O.X. 1 filter the supplementary ultra-violet light. Where stray red lig through the O.X. 1 is a disadvantage, the modified O.X. O.B. 10 filter and a lamp at 3000° K are suggested.

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Automatic correction for paralysis in Geiger counting

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A simple and inexpensive attachment to a standard probe and scaler unit is described which provides an automatic correction to the scaler reading in radioactive assays using Geiger counters. Over the usual range of operation of these counters, 0 to 16 000 impulses/min, the relative errors in the scaler reading due to paralysis of the counting system are thus reduced to 0·3 %.

To allow a Geiger counter to recover after an ion burst, a period called the paralysis time is selected in the counting apparatus. During this period counts usually referred to as "lost counts" may be received but will not be recorded by a scaler. A correction for lost counts is made using a relationship of the form(1)

$$N = n + TnN \qquad (1)$$

N being the corrected count rate, n the recorded count rate and T the paralysis time. To obviate the repetitive calculation involved in the application of formula (1) when many samples are to be assayed a means has been developed whereby an automatic correction may be made. This problem has already received some attention by others and E. W. Pulsford,(2) for example, has discussed a solution of this problem in his design of a counting rate meter. The device described here, however, was designed to be inserted into existing Geiger counting apparatus with the minimum of modification.

PRINCIPLE

Suppose that the paralysis time of the counting apparatus is t μs so that impulses received between 0 and t will not be recorded. Suppose a time α is chosen so that the number of impulses received between t and α is equal to that received between 0 and t.

Following Brownlee,(3)

$$1 - e^{-mt} = e^{-mt} - e^{-m\alpha}$$

where m is the mean count per microsecond. Thus,

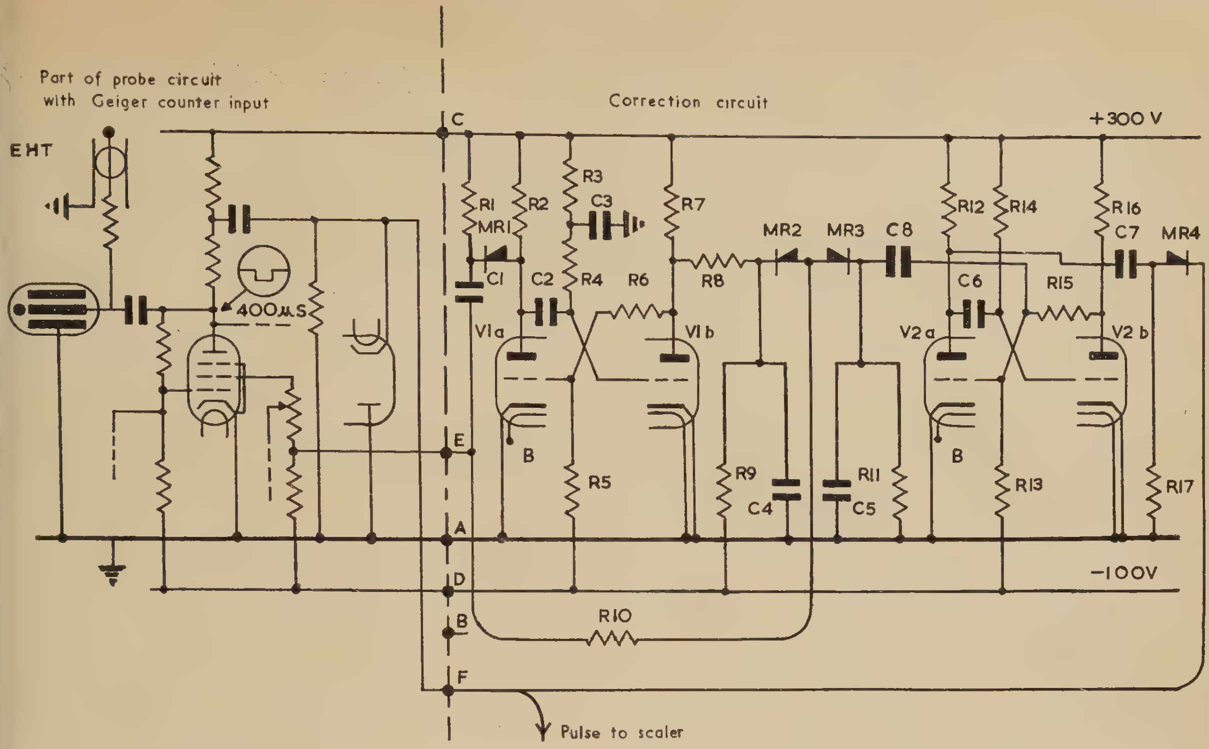
$$1 - 2e^{-mt} = - e^{-m\alpha}$$

$$\alpha = - \frac{\log (2e^{-mt} - 1)}{m}$$

and varies from 800 μs to 890 μs over a range in m fro 10^{-6} to 5×10^{-4} mean counts/μs, i.e. covering the extrem operational range for Geiger counters. The variation in with m over this range is approximately linear. The electronic device described here is so designed all that impulse received during the second time interval, i.e. between t an α, are doubled so allowing for the counts lost between 0 and

CIRCUIT

The circuit diagram shows the correction circuit, wit input taken from a standard probe unit. The probe is monostable multivibrator formed by two pentodes, whic generates a pulse of 400 μs duration for each input puls from the Geiger counter. One of the pentodes is shown o the diagram, from the anode of this valve, output F will fee positive pulses to operate the scaler. In the screen circui output E is arranged to feed a positive pulse of 400 μ duration to the correction circuit. At the termination of pulse at E the first monostable multivibrator V_1 a, b, i triggered. This is arranged by differentiating input E b C_1, R_1, and selecting the negative pulse. The pulse produce at the anode of V_1 b, is of variable duration from 400 t



Circuit diagram

R_1, R_{10}, R_{15} = 220 kΩ
R_2, R_7, R_{12}, R_{16} = 47 kΩ
R_3 = 3·86 MΩ
R_4 = 910 kΩ
R_5, R_6 = 560 kΩ
R_8, R_9 = 100 kΩ
R_{11} = 470 kΩ
R_{13} = 330 kΩ

R_{14} = 2 MΩ
R_{17} = 7·5 kΩ

C_1, C_2 = 220 pF
C_3 = 2680 pF
C_4 = 1000 pF
C_5, C_8 = 330 pF

C_6 = 100 pF
C_7 = 470 pF

V_1 = ECC91
V_2 = ECC91

MR_1 = K8/10T
MR_2 = K3/3T

MR_3 = GJ3M
MR_4 = GJ3M

R_3 adjusted with input rate of 600 impulses/min

C_3 adjusted with input rate of 16 000 impulses/min

μs dependent on the input pulse rate. This pulse con-
s the selection period of the gate circuit MR_2 MR_3 the
ut to the gate being taken directly from the probe at *E*.
pulse occurs at *E* during the selection period it will be
epted to trigger the second monostable multivibrator
a, *b*. At the anode of V_2 *a*, a negative pulse is generated
00 μs duration, the pulse is differentiated by C_7, R_{17}, and
positive pulse is selected to feed the scaler. This ensures
t the correction pulse is injected to the scaler 200 μs after
gated pulse, and occurs at the midpoint of the paralysis
iod. Approximate correction of α for the variation with
int rate, is ensured by R_3, C_3.

RESULTS

comparison between the reading of the scaler when the
omatic correction device is included and the scaler reading when corrected in the usual way by formula (1), is shown in the Table. The range required was from 0 to 16 000 impulses/min, and over this range the relative error is within 0·3%. Beyond 16 000 impulses/min, the linear relationship between α and the impulse rate is no longer maintained by the simple circuit used.

Normal correction impulses/min	*Automatic correction impulses/min*	*% Error*
27 387	27 768	1·4%
20 947	21 111	0·8%
16 308	16 353	0·3%
12 623	12 629	0·1%
9 864	9 855	0·1%
7 140	7 147	0·1%
4 404	4 400	0·2%
1 805	1 806	0·1%
150	150	0·1%

PRACTICAL NOTES

The correction device was designed to follow a standard probe unit (Harwell type 1014A) and to derive its heater and high tension supplies from the scaler. The resolving power of the scaler must of course be better than 200 μs.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of Dr. G. E. Harrison in the preparation of the paper and of Mr. T. Hobson for the calculations involved in the principle.

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Controlled atmosphere levitation system

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A levitation system designed to melt and cast small quantities of metals under controlled-atmosphere conditions is described. Temperature control of the levitated sample and certain other practical aspects of the technique are discussed on the basis of experience gained over a two-year development period.

As part of a project covering the metallurgy of the reactive metals, melting techniques such as electric-arc melting in a water-cooled copper crucible, drip melting of a rod of metal held in a high-frequency coil, and levitation melting have been extensively used in this laboratory. A levitation unit designed to melt and cast small quantities of metals under controlled-atmosphere conditions has proved to be a most useful laboratory instrument, particularly in preparing extremely pure alloys in quantities of up to 15 g in weight.

Levitation of a metal or other conductor is produced when a diverging field, caused by a high-frequency current in a suitably shaped coil, is used to induce a current in the conducting material placed within the coil. The induced current heats the conductor and, by interaction with the field, produces a lifting and a centralizing force. A piece of metal placed in the field of such a coil adopts a free position in space and may eventually melt, when the molten mass will rotate very rapidly and tend to assume the contour of the coil. By reducing the field strength, the metal may be cast from the coil. Fig. 1 shows silver "pouring" from the coil into a copper mould.

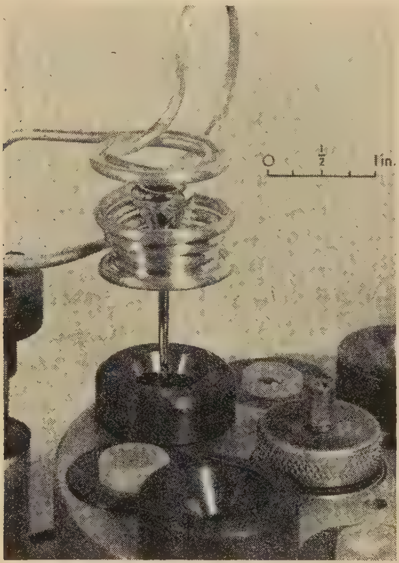

Fig. 1. Silver "pouring" from coil into copper mould. Silica boats are shown in position

PRINCIPLES OF LEVITATION

A conductor placed in a non-uniform alternating electromagnetic field tends to move from the stronger to the weaker part of the field. The force on the conductor due to the field is associated with both the strength and the gradient of the field—the steeper the gradient, the greater the force. F levitation, a field is required which decreases in strength in vertical direction so that an upward force equal to the weig of the conductor can be obtained and, for lateral stability field is required which increases in strength radially from t field axis so that a restoring force operates towards the ax

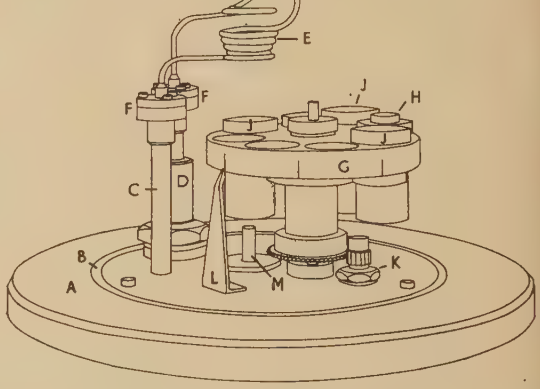

Fig. 2. Diagram of levitation unit above base plate. Vacuum line is behind carriage

The methods(1,2) so far used to obtain such a field requ the use of two coils, one above the other, the currents in eac being out of phase. In this way it is possible to obtain position of minimum field strength between the two coils that the forces on a conductor between them are alway towards this point, thus producing the conditions necessa for stable levitation. Because the levitation force is associate with the divergence (field-strength gradient) of the field as we as the field strength, and because the heating of the conduct is associated with the field strength, it is possible to decrea the heating rate (and therefore the equilibrium temperatur by increasing the field divergence and decreasing the fie strength. In the coil system to be described, this can achieved simply by increasing the coil current when the con ductor rises to a more divergent part of the field closer to th point of minimum field strength.

DESCRIPTION OF UNIT

The levitation unit (Fig. 2) consists of a brass base plate over which a glass bell is placed, the junction being sealed an O-ring *B* recessed in the base plate, The bell is clampe to the base when operating at gas pressures approaching above atmospheric. The system is evacuated through a in. line by means of a mercury diffusion pump backed by rotary pump. The pressure is measured with a Pirani gaug and a bellows gauge calibrated from 0–2 atmospheres. Ga if required, is admitted to the system through a magneticall rated valve, the back filling pressure being controlled by a ssure switch to any preset value. The unit is operated n a 6 kW, 400 kc/s Radyne (by Radio Heaters Ltd.) power rce, the power output of which is controlled from the front el of the levitation unit. The high-frequency leads are ught through the base plate: the earthed lead *C* is soldered ctly through the base whereas the high-tension lead *D* is nodified high-voltage vacuum assembly (Type No. 8, by vards High Vacuum Ltd.) in which the solid conductor is laced by a copper tube. The actual levitation coil *E* is nected to the leads by O-ring seals *F*. The high-frequency nexions from the generator to the coil are placed close ether to minimize their inductance.

carriage *G*, containing samples held in silica boats *H*, and ulds *J*, may be rotated by a shaft brought through an O-g seal *K* in the base plate, and permits either a sample or a uld to be placed directly under the coil, the pointer *L* icating the correct position. The samples are lifted into coil by a push rod *M* operated by a magnet situated outside vacuum system. Both the carriage rotation and the nple lift are operated from the front of the unit. The sent system is designed to levitate, melt and cast four nples without breaking the gas system, but the number of nples handled could be increased by re-designing the sample-dling system. Cylindrical split-copper moulds are used, these could be modified if special shapes were required.

he coil design used is based on that described previously lonis and others(3, 4, 5)) but it has been modified to give ater lateral stability to molten charges. The existing coil sists of seven turns of *a* in. o.d. silver tubing, the two lower ns of which are co-planar, whilst the next three form a 45° e with the inner turn. Two co-planar reversed turns are ced directly above the cone, the inner turn having a diameter al to that of the inner turn of the lower coil (that is, $\frac{3}{4}$ in.). lower co-planar turns are equivalent to a turn of smaller meter, and produce good stability of the liquid charge, ticularly in respect of dripping of the melt. The two planar reverse turns produce high lateral stability and vent a levitated sample touching the side of the coil.

he existing coil produces a field in which the divergence ies with the position in the coil, the field being nearly allel at the bottom and highly divergent between the two ls, with a point of minimum strength to which the levitated nple tends to move. A second coil, consisting of four ver turns, two pairs of co-planar turns, and four similar erse turns above, has been found to give high stability to all levitated samples, and permits levitation inside a glass e with the coil outside. This simplifies the vacuum system d lowers the volume of the system to less than 100 ml and proved useful in investigating equilibrium in metal/gas tems.

The capacity of the present unit is approximately 10–15 g metal. Experience with titanium has shown that 10 g y be levitated with ease, and the limit with silver is 15 g. ss of metal by volatilization varies with the metal and the nperature, but is seldom troublesome because molten itated charges experience extremely rapid stirring, and less n one minute is sufficient to produce a homogeneous melt. sses suffered in alloying are therefore scarcely detectable d, if volatilization must be further restricted, it is possible exercise closer control, provided small charges are used.

TEMPERATURE OF LEVITATED SAMPLES

In the study of metal/gas equilibria (or for similar physico-emical applications), close control must be held over the temperature of levitated specimens. The physical factors of importance in this connexion are the electrical resistivity and the density of the specimen. Low electrical conductivity causes high resistance losses and, hence, a high temperature is attained. High-density materials require a high field strength to produce levitation and a high temperature results.

The mass of the sample levitated and its position in the coil are important factors affecting the equilibrium temperatures. Samples of most metals weighing about 10 g eventually reach temperatures greatly in excess of their melting points and vaporization becomes appreciable. For alloy preparations this is not important because the alloy may generally be cast before losses by volatilization become significant. Small samples of titanium weighing about 0·5 g may be levitated at temperatures well below the melting point. By reducing the power input to the coil, the sample takes up a new position lower in the coil where the field strength is greater and the field less divergent, thus producing greater heating for the same lifting force. In this way, small amounts of titanium may be melted and re-solidified while remaining levitated, or they may be held at any temperature within the range 1000–2000° C for periods in excess of two hours.

The amount of energy lost by radiation at a given temperature depends upon the surface area of the sample and the emissivity of the surface. For any one sample in the molten state, these variables are fixed and cannot be used as a means of temperature control. The heat lost by conduction depends upon the gas pressure and upon its composition. For a sample of titanium levitated in argon under a pressure of one atmosphere, the temperature change caused by changing the gas pressure by 50% was 10° C. A one-gram sample of copper levitated in argon reached a temperature of over 1400° C, whereas, in a hydrogen atmosphere, the levitated copper did not melt. Similar results should be obtained using a helium atmosphere, and this will probably allow larger samples of the reactive metals to be levitated for long periods without suffering losses by vaporization.

Cooling of levitated samples may also be achieved by forcing gas past their surface. In this way, small samples have been cooled to a few hundred degrees without upsetting the stability of the sample in the coil. Samples have also been levitated under liquids, and a sample of cobalt levitated under water exhibited two equilibrium states. When the cobalt was levitated after being placed under the water, the sample remained cool, but, when the cobalt was first levitated and then surrounded by water, it remained hot because of the existence of an insulating layer of steam. Under these conditions the cobalt could be melted.

CONCLUSION

The levitation unit described has been successfully applied over a two-year period to the production of small homogeneous samples of extremely pure alloys. Many metals, including silver, copper, aluminium, iron, silicon, cobalt, nickel, titanium and zirconium, have been levitated and melted. Graphite levitates readily and can then be reacted with metals. The unit also offers unique conditions for the study of gas/metal equilibria and nucleation phenomena.(6)

ACKNOWLEDGEMENTS

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Infra-red absorptiometer, using interference filters, for analysis of hydrogen fluoride in gaseous mixtures

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A wavelength-scanning infra-red absorptiometer using interference filters has been developed for analysis of hydrogen fluoride in corrosive gas mixtures. The wavelength scanning is achieved by tilting an interference filter at 10 c/s, thus passing alternate beams of different wavelength through the same sample tube. Only one of the beams is absorbed by hydrogen fluoride, while the other is used as a reference beam; a difference signal depending on the partial pressure of hydrogen fluoride is measured. Using this principle, the instrument has been designed so that the calibration is independent of corrosion of the windows of the absorption tube. The prototype instrument detects partial pressures of hydrogen fluoride in the range 0·02–20 mm of mercury in 1 atm of the mixture.

Optical absorptiometers can often be used to measure the amount of constituent in a gas or liquid mixture. The accuracy of conventional instruments, however, may be seriously affected by the sample cell windows being corroded or obscured when measuring corrosive mixtures.

An absorptiometer, using interference filters, which is self-compensating for loss of cell transmissions has been developed. The instrument is designed to measure the concentration of hydrogen fluoride in a highly corrosive gas mixture which also may contain uranium hexafluoride, nitrogen and traces of inter-halogen compounds. It is the subject of a provisional patent application.(1)

PRINCIPLES

Several instruments using interference filters have already been described, e.g. by Parsons, Irland and Bryan,(2) but these use filters as simple monochromators. An advantage is gained if use is made of some of the special properties of the filters. Heavens(3) and Smith,(4) amongst others, outline the construction and general properties of various designs of filter.

An important property of the etalon type of filter is the manner in which the transmitted wavelength can be varied by altering the angle of incidence of the light. The change in wavelength is given by:

$$d\lambda = -\tan\alpha \, . \, d\alpha \qquad (1)$$

where λ = wavelength of transmission maximum;
α = angle of incidence of the light at the etalon spacer.

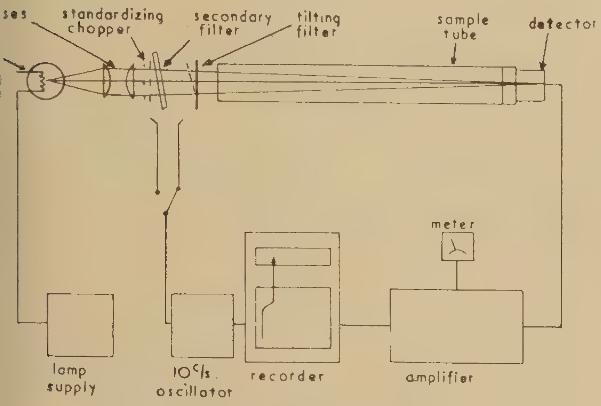
This property of filters is used in the absorptiomet described here.

The instrument passes two light beams of differing wav length through the sample tube, one beam being at wavelength characteristic of the sample and the second an adjacent wavelength clear of absorption. The two bea are shone alternately on the detector which thus produc an electric signal depending on the difference in intensity the two beams. The figure shows the arrangement of th instrument. Any loss of sample cell transmission, caus for example by window corrosion or obscuring, will affe equally both sample and comparison beams. This syste therefore allows variation of sample cell characteristics to b compensated.

DESCRIPTION OF THE INSTRUMENT

The primary absorption bands of hydrogen fluoride lie i the region of $2{\cdot}5\ \mu$,(5, 6) which is nearer to the visible regio than any bands of the other gases in the corrosive gas mixtu being examined. The components of the instrument a mounted in line, as shown in the Figure, on a rigid steel be White light from the tungsten lamp (a vehicle headlamp bul 48 W, 12 V), which is supplied from a stabilized electron power supply, passes through the collimating lenses and t standardizing shutter to the interference filters.

The two filters which are used to select a beam of ligh monochromatic to within about $0{\cdot}004\ \mu$, were made in th laboratory. The wide-band filter (the secondary filter in th figure) consists of evaporated germanium and cryolite on glass base, and serves to reject all light except that lyin een about 2·0 and 2·5 μ. The other filter is a narrow- l interference filter comprising a central layer of mica from cleavage steps) with a germanium–cryolite– anium reflector on each face. The mica is about 40 μ , and the germanium and cryolite layers have a thickness /4, where λ is approximately 2·45 μ (a wavelength in the amental band of the hydrogen fluoride molecular trum). This filter has a number of pass bands approxi- ely equally spaced within the wavelength range 2·3–2·5 μ. pass band is very narrow (0·004 μ) compared with the nce between the bands 0·05 μ. The actual wavelength ach band depends on the angle which the filter makes the incident light.



Wavelength-scanning absorptiometer

he mica filter is mounted on the armature of a relay h is energized at a frequency of 10 c/s, so that the filter lted ten times per second through an angle of about 3°. h the relay unenergized the mica filter passes light of a ber of wavelengths, including one of the same wave- th (λ_0) as one of the rotational lines of the hydrogen ride spectrum; when tilted it passes light of a wavelength intermediate between two of the rotational lines. Thus light entering the sample tube alternates continuously veen λ_0 and λ_1 at a frequency of 10 c/s. The other wave- ths which the mica filter passes are of no consequence, vided that (*a*) the sum of their intensities does not drive photocell into non-linearity, and (*b*) none coincide with hydrogen fluoride bands in the λ_1 position. The uranium afluoride and other gases are arranged to purge the nel sample tube as rapidly as may be required.

hoice of a suitable material for the end windows of the presented some difficulty, because most transparent stances are attacked by uranium hexafluoride, hydrogen ride, or interhalogen compounds. Polytrifluorochloro- lene was found to have the desired properties. This stance, which is not unlike polythene, has a milky appear- but is more transparent in the infra-red than in the ble region. Disks 2 mm thick and 30 mm in diameter e as their own vacuum seals when clamped against a p edge. The light which passes through the sample tube ceived by the detector. A suitable detector for this range wavelengths is a photoconductive type containing a lead hide sensitive element (e.g. Mullard type 61 SV).

he instrument is adjusted by rotating the secondary filter ut a vertical axis until the intensities I_{λ_0} and I_{λ_1} are equal, no hydrogen fluoride in the sample tube. In this dition the signal from the detector is almost pure d.c. contains no 10 c/s component (there may be a little 20 c/s component due to the finite change-over time of the relay). This signal is fed to an a.c. amplifier tuned to 10 c/s, which then gives zero output for no hydrogen fluoride. When a partial pressure of hydrogen fluoride is introduced, light of wavelength λ_0 is partly absorbed and so reduced in intensity, while λ_1 remains undiminished; a 10 c/s optical signal of peak-to-peak amplitude $(I_{\lambda_1} - I_{\lambda_0})$ appears at the detector, and the resulting voltage is amplified and displayed. Provided that (*a*) I_{λ_1} and I_{λ_0} remain equal for no hydrogen fluoride in the tube, and (*b*) I_{λ_1} does not vary, the difference $(I_{\lambda_1} - I_{\lambda_0})$ is a measure of the partial pressure of the hydrogen fluoride present.

Condition (*a*) depends on the temperature of the lamp remaining constant; this is achieved by feeding it from a stabilized power supply, the lamp being under-run to ensure long life. Condition (*b*) is impossible to maintain, because of corrosion of the absorption tube windows. Compensation can be made, however, by adjusting the gain of the 10 c/s amplifier, as follows. The mica filter is left at rest passing the λ_1 beam while the standardizing shutter is fed with the 10 c/s signal. The gain of the amplifier, which now includes a 100-to-1 attenuator, is adjusted to give a standard output. This method of standardizing also corrects for changes in the detector sensitivity. The standardizing sequence can conveniently be made automatic, if the signal is displayed on a recorder, by using the standardizing mechanism which is built into most recorders.

The specifications of the three electronic units are:

(i) current-stabilized power supply giving 20 W ± 0·2%;
(ii) 10 c/s square-wave generator with an output of 1 W;
(iii) 10 c/s a.c. amplifier with a gain of 10^6 incorporating a rectifier, smoothing circuit and 0–100 microammeter or 0–10 millivolt recorder.

CALIBRATION

Smith(7) and Gaunt and Deane(8) have shown that the calibration of an absorptiometer detecting hydrogen fluoride does not follow Beer and Lambert's law, and that a better expression is:

$$T_x = T_0 \exp(-\beta p l^{1/2})$$

where T_x = integrated transmission intensity in the presence of hydrogen fluoride;
T_0 = integrated transmission intensity for blank sample;
p = gas pressure;
l = length of absorption tube;
β = a coefficient, the value of which is a function of the absorptiometer.

Since β can be evaluated only by experiment, no absorptiometer can be given an absolute calibration.

The molecular spectrum of hydrogen fluoride shows considerable broadening of the absorption lines if foreign gases are present. Kuipers(9) and Gaunt and Deane,(8) amongst others, deal with this phenomenon. Some broadening coefficients have been evaluated by Smith(7) and Gaunt and Deane.(8)

The relationship given by Gaunt and Deane is:

$$\left(\frac{d_n}{d}\right)^2 - 1 = \frac{bp_n}{p}\left(1 - \frac{xp_n}{p} + \frac{x^2p_n^2}{2p} \quad \ldots\right) \tag{2}$$

where d_n = optical density of pure hydrogen fluoride $-[ln(T_0/T)]$;

d = optical density of hydrogen fluoride with a second gas [$= ln(T_0/T_n)$];
p_n = partial pressure of foreign gas (mm of mercury);
p = partial pressure of hydrogen fluoride (mm of mercury);
x = a constant;
b = a constant;
T_0 = integrated incident intensity;
T = transmitted intensity for p (mm of mercury) of hydrogen fluoride alone;
T_n = transmitted intensity for p (mm of mercury) of hydrogen fluoride and p_n (mm of mercury) of foreign gas.

Since the constants x and b do not depend on instrumental factors, it is possible to use them for reducing measurements made on any instrument under any conditions of resolution without further adjustment.

The filtered instrument described here does not measure T or T_0, however, but $(T_0 - T) = S$ (say), where S is the signal reaching the photocell with a sample of pure hydrogen fluoride in the tube, or $(T_0 - T_n) = S_n$, where S_n is the signal with a binary mixture containing hydrogen fluoride.

It can be shown that $S_n/S = d_n/d$, provided that $T_0 - T_n \ll T_0$.

Hence
$$\left(\frac{S_n}{S}\right)^2 = \frac{bp_n}{p}\left(1 - \frac{xp_n}{p} + \frac{x^2p_n^2}{2p} - \ldots\right) \qquad (3)$$

Equation (3) can be re-arranged in the approximate form:
$$S_n = A\sqrt{(p^2 + bp_np)} \qquad (4)$$
where A is a constant of the instrument. This expression is valid when S is small and p_n large.

For normal applications, where the pressure of hydrogen fluoride is a small fraction of the foreign gas pressure, equation (4) is used for calibrating the instrument; the constant A is determined experimentally, using known gas mixtures.

The broadening constants of uranium hexafluoride and nitrogen are very similar; so that it is reasonable to calibrate the instrument on mixtures of hydrogen fluoride and nitrogen, and to use the calibration thus obtained for mixtures containing uranium hexafluoride.

Temperature variations will also cause some changes in absorption line profile which would affect the calibration. However, for the application for which the instrument was designed, the gas temperature is substantially constant, and hence no temperature compensation is necessary.

DISCUSSION

No special precautions were taken to make the instrument as sensitive as possible, as it was only desired to measure partial pressures of hydrogen fluoride between 5 and 20 mm of mercury. It was found, however, that 0·02 mm of mercury was the minimum detectable partial pressure of hydrogen fluoride in 1 atm of nitrogen. Sensitivity is unlikely to be improved by lengthening the absorption tube, because the optical density of the path only increases as $l^{1/2}$, and t light intensity may fall off as l^2 unless it is very carefu collimated.

The narrow-band mica filter lends itself to several m elegant methods of scanning from λ_0 to λ_1 and back. F instance, by making the filter from a disk of mica with cleavage edge across the diameter, it should be possible make one half transmit λ_1 and the other half λ_0. The di could then be rotated on an electric motor shaft which cou carry contacts to provide synchronous rectification for t signal from the amplifier. With this system the mica fil would be less likely to suffer mechanical damage, and t synchronous rectifier should reduce the noise level and increase the sensitivity. It is hoped to incorporate these alternative features in a later form of absorptiometer.

CONCLUSION

The instrument described will measure partial pressures hydrogen fluoride down to 0·02 mm of mercury in mixt of hydrogen fluoride, nitrogen and uranium hexafluor The prototype has been used continuously for six months routine analysis of such mixtures.

ACKNOWLEDGEMENTS

Mr. D. F. Davidson was responsible for the design of t electronic parts of the instruments. This paper is publis by permission of the Managing Director of the Indus Group, United Kingdom Atomic Energy Authority.

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trical method for detection of transition of atomization type in centrifugal atomizers

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[*Note first received* 24 *September, and in final form* 4 *December*, 1958]

following symbols are used in this note: Q, liquid feed ; $D = 2R_2$, disk diameter; σ, surface tension of liquid; ensity of liquid; μ, viscosity of liquid; ω, disk speed; inner radius of sleeve.

the production of sprays by the disintegration of a d on a spinning disk, or other centrifugal atomiser, e are three possible modes of atomization: (*a*) dropwise, igament, (*c*) film. These may be broadly distinguished ollows. For a given liquid, disk and speed of rotation, n the liquid feed rate is small the droplets are disengaged vidually from the disk periphery. As the flow is increased, nents extend outwards from the disk. They are roughly lute in shape and these ligaments break into droplets as nsequence of their instability. With still greater values ow the ligaments become unable to deal with the quantity iquid involved, and a spinning sheet of water, which tures at the edges, surrounds the disk. The existence of e several modes of atomization is known as a result of -speed photography, and photographs of ligaments may ound in papers by Pattison and Aldridge,(1) Hinze and oorn,(2) and by Golitzine.(3)

he difficulties associated with the photography of small ions of fast moving disk periphery could be avoided if liquid itself could be used for maintaining current in an tric circuit so that the supervention of dropwise atomiza- with the production of discrete droplets caused the uit to be broken.

ome experiments were conducted to test this method and 1 shows the simple circuit employed. The disk *A* was of the main atomizing plant(4) and this was surrounded a short concentric copper sleeve *B*. The top of both and sleeve lay in the same plane and the sleeve extended iciently far downward to ensure that the whole of the y impinged thereon.

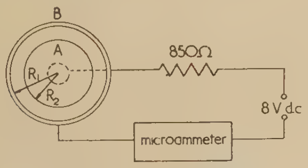

Fig. 1. Circuit

number of factors govern the choice of the gap. Thus existence of the sleeve must not disturb the air boundary r surrounding the disk or atomization may be different and without the sleeve. To determine the radial extent he boundary layer an experiment was conducted using a n diameter disk at speeds from 20 000–45 000 rev/min. adial Pitot traverse was undertaken and Fig. 2 shows the ilts obtained, the ordinates being head readings in cm of hol as obtained using a high accuracy manometer. Air cities corresponding to the head are also added. It will observed that the high velocity portion of the boundary layer is very localized in extent with a smooth-edged disk, but that some air movement extends beyond the maximum plotted position for which the gap is 0·5 mm. The decline of head with increasing gap is approximately exponential. It was also found that liquid tended to collect on the sleeve until sufficient had accumulated to fall off by gravity and that with a gap of the order of 2 mm it was possible for accumulated liquid to span the gap and invalidate the results.

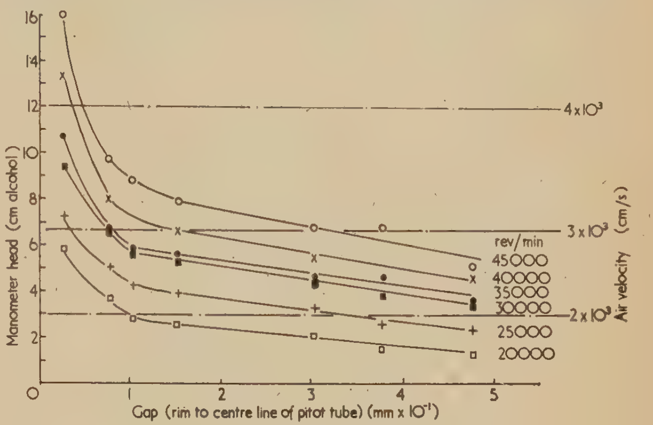

Fig. 2. Air boundary layer thickness

The choice of the gap is also influenced for ligament atomization by the stable length of the ligament. Assuming ligaments of true involute shape it may be shown that the length of a ligament between its root at the disk and the end at the sleeve is

$$(R_2^2 - R_1^2)/2R_1 \qquad (1)$$

The ligament is required to be stable for this length. Rayleigh(5) found that liquid columns are unstable by the effects of surface tension alone for disturbances of rotational symmetry having a wavelength λ where

$$\lambda > \pi d \qquad (2)$$

d being the column diameter. Unfortunately, it is not possible, other than by photography to establish the value of d, nor is equation (2) capable of ready interpretation for a column having continuous axial curvature. It would seem therefore that an analytical approach to determine the stable ligament length cannot be made. Photographs do, however, suggest that at least with the more viscous liquids the ligament length is sufficient to enable a sleeve to be placed at an acceptable distance from the disk. A disk of 4 cm diameter was employed and the gap $R_2 - R_1$ was 3·75 mm.

The flow of current to be expected in the circuit is shown in Fig. 3. For the dropwise regime *AB*, no current will flow. With the onset of ligament formation the current will rise as the number and diameter of the ligaments increase. At some point *C*, ligaments will degenerate into a film and the current will continue to rise slowly until it becomes equal to the value corresponding to a short circuit between disk and sleeve.

Fig. 4 shows the curve actually obtained using salt water. Salt has the property, in this connexion, of rendering the water electrically conducting without materially altering its surface tension. The curves of Figs. 3 and 4 are seen to be generally similar, but it is necessary to relate the curves and to show whether the point X of Fig. 4 corresponds to B or to C of Fig. 3.

The ligament/film transition was studied by Hinze and Milborn⁽²⁾ for rotating cups and it was shown that transition occurred when

$$\frac{Q}{D}\sqrt{\frac{\rho}{\sigma D}}\left(\omega D\sqrt{\frac{\rho D}{\sigma}}\right)^{0\cdot 6}\left(\frac{\mu}{\sqrt{\rho\sigma D}}\right)^{0\cdot 167} > 133 \qquad (3)$$

The boundary line thus defined is shown in Fig. 5 which is reproduced from their paper. The value of the groups $\omega D\sqrt{\frac{\rho D}{\sigma}}$ and $\frac{Q}{D}\sqrt{\frac{\rho}{\sigma D}}\left(\frac{\mu}{\sqrt{\rho\sigma D}}\right)^{1/6}$ were calculated for point X and gave $2{\cdot}94 \times 10^3$ and $1{\cdot}95 \times 10^{-2}$ respectively.

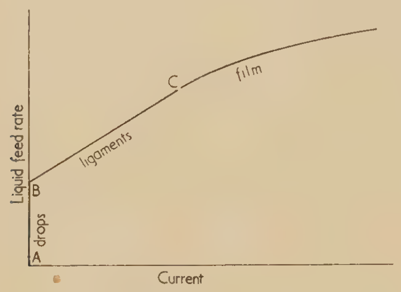

Fig. 3. Expected variation of current with feed rate

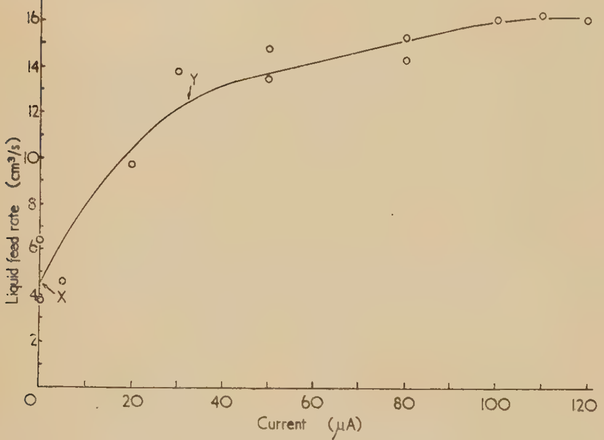

Fig. 4. Experimental variation of current with feed rate

A point Y was also chosen from about the centre of the bend in the experimental curve (Fig. 4) and the respective values of these groups were also calculated for point Y giving respectively $1{\cdot}96 \times 10^3$ and $5{\cdot}41 \times 10^{-2}$. Inspection of the respective placings of X and Y on Fig. 5 shows that X on Fig. 4 corresponds to C on Fig. 3, so that the experimental curve covers film type atomization.

CONCLUSIONS AND COMMENTS

It was noticed that no measurable current was obtained for a flow rate of less than about 4 cm³/s. This must be taken to indicate either that the current was too small for measurement or that ligaments broke up within the 3·75 mm gap. The method would be much improved if the sleeve were itself rotated to clear the accumulated liquid.

Trouble was experienced due to the accumulation of spray on insulated items in the vicinity of the disk which promoted small leakage currents and led to the necessity of shieldi and wetness inhibition.

Despite the difficulties mentioned, the experiments indic that the method is sound in conception and could developed further, thus avoiding the lengthier and l convenient method of photography.

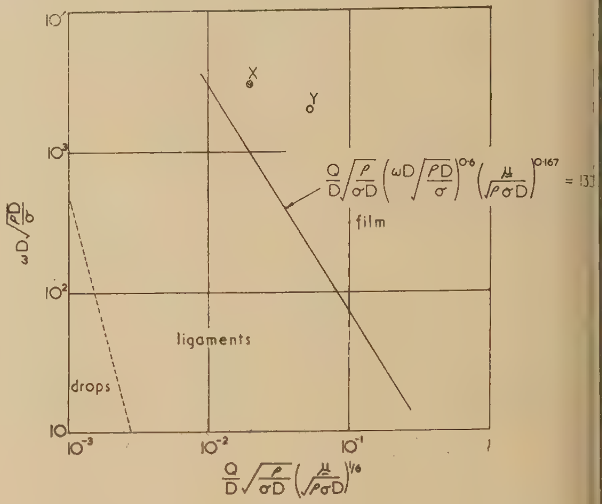

Fig. 5. Placing of experimental points relative to Hinze–Milborn transition boundary

ACKNOWLEDGEMENTS

The writer is indebted to Prof. W. J. Kearton, late Harr Professor of Mechanical Engineering in the University Liverpool for permission to use departmental facilities.

He is also indebted to Dr. H. W. Douglas, of Department of Inorganic and Physical Chemistry, for helpful discussion.

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Optical joint for horizontal mounting of a large scintillati crystal

By G. L. Olde, M.Sc., and E. Brannen, Ph.D., Department of Physics, University of Western Ontario, London, Canada

[*Note first received* 22 *September, and in final form* 10 *November*, 1958]

During work recently done in this laboratory on the c struction of a total absorption spectrometer, difficulty w experienced in obtaining good optical contact between 4 × 5 in. NaI (Tl) crystal and a type 6364 phototube (Allen B. DuMont Laboratories Inc.). It was necessary mount the crystal-phototube unit with the axis of the phot tube horizontal, and in this position even high viscos ne oil gradually leaked out from interface, thereby y reducing the efficiency of the optical contact. e approach to this problem has been suggested recently mohundro,* who has developed a coupling cement n gives a strong bond between the crystal and phototube ces, and leads to a light output equal or superior to obtained using heavy mineral oil.

ile trying to obtain a good optical joint, several materials line or white petroleum jelly, silicone stopcock grease, others) were tried, but, although they did not flow away the contact surface, their opacity was great enough in case to greatly reduce the efficiency of the optical ct. Therefore, silicone oil, of viscosity 10^6 cs, was pted as the most suitable contact material. The final gement employed an O-ring and a band, roughly 3 in. by $\frac{1}{8}$ in. thick, made from liquid latex. The preparation e optical contact was then carried out as follows. A layer of silicone oil was spread on the contact surfaces he O-ring was placed in position. A press fit was made een the contact surfaces while the crystal-phototube unit maintained in a vertical position. The latex band was ped into position and the edges fastened to the crystal the photomultiplier with electrical tape. The assembly placed in the spectrometer chassis and a constant pressure ed between the crystal and the phototube by means of mping device. A small hole was cut in the uppermost ce of the latex band and silicone oil poured in until the e between the crystal and the phototube was completely . This arrangement, as shown diagrammatically in the re, has shown no leakage over a six-month period and optical contact efficiency has remained substantially the e. With this optical joint, a resolution of 11% for ^{137}Cs ratio of 12 : 1 for photopeak to Compton background e obtained with the source 50 cm from the collimator.

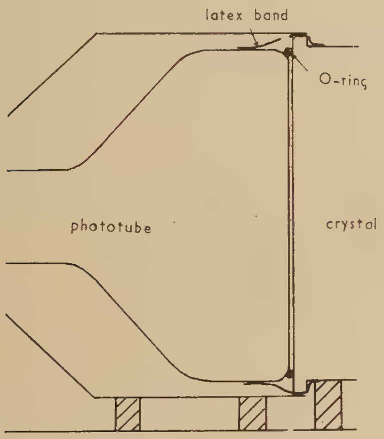

Diagram of optical joint

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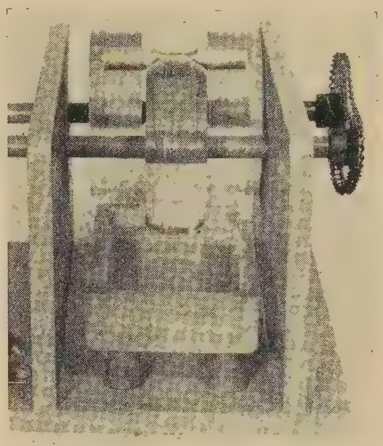
* Omohundro, R. J. *Rev. Sci. Instrum.*, **29**, 893 (1958).

Acid machining of cylindrical crystals

By T. Broom, M.A., Ph.D., and J. M. Summerton, B.Sc.,
Department of Industrial Metallurgy, University of Birmingham

[*Note received* 9 *October*, 1958]

In conventional acid-machining procedures, a slowly-rotating crystal is lightly rested upon a rotating profiled wheel which carries a thin film of acid from a bath placed beneath it.* Because single crystals are usually mechanically weak, heavy loads which would cause deformation are avoided by employing a counterpoise to the crystal and its driving motor. In the apparatus shown in the figure, the crystal simply rests upon three wheels arranged tricycle-fashion with the single wheel over-lapped by the outer two. The single wheel is machined to the reverse profile of that required for the crystal and dips into a bath of acid. The outer wheels serve to rotate the crystal and are flanged so as to prevent endways movement of the crystal. In the present arrangement the wheels and acid bath have conveniently been made of Perspex. The outer driving wheels are rotated at about 20 rev/min and the machining wheel is connected *via* a chain drive to run in the same sense at 50 rev/min. The sense is such that the machining wheel tends to push the specimens into the gap between the wheels. Using dilute nitric acid, gauge lengths 4 mm diameter × 10 mm long have been machined in 10 mm diameter zinc crystals in 1–2 h. The variation in diameter along a gauge length is usually less than 2% and axiality with the ends of the crystal is excellent. A few copper crystals have also successfully been machined. Should more rapid machining be desirable, slight modifications could be made to permit electrolytic machining.



Arrangement for acid machining of cylindrical crystals

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* Parker, E. R., and Washburn, J.: *Modern Research Techniques in Physical Metallurgy*, p. 186 (Cleveland, Ohio: American Society of Metals, 1953).

Correspondence

Obliquity corrections in transmission interference microscopes

Ingelstam and Johansson⁽¹⁾ have reported on the correction due to aperture in transmission interference microscopes and refer to the fact that the correction is opposite in sign to that found for reflexion microscopes. The correction in the latter has been discussed by Tolmon and Wood,⁽²⁾ Gates⁽³⁾ and Bruce and Thornton.⁽⁴⁾ Discussion with other workers has revealed a possible misunderstanding about this difference of sign. Hale⁽⁵⁾ has also referred to obliquity corrections for both reflexion and transmission microscopes without distinction of sign.

Reflexion interference microscopes are practically always used to examine surface irregularities, and the two interfering wavefronts originate from the surface of the object and the reference surface (Fig. 1). The optical path difference of a small object of height t is $\Delta = 2nt \cos\theta$ and hence a positive correction should be applied for obliquity angles θ up to that of the whole aperture. This of course applies equally well in the case where the thickness of a thin transparent film is measured by transmission fringes.

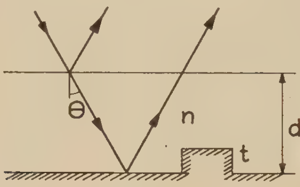

Fig. 1. The reflexion interference microscope case. The light beam is reflected firstly from a plane reference surface and secondly from the object surface, containing a small elevation with the height t. The refractive index of the medium around the object is n, and the incident angle θ. The path difference between the wavefronts, that is reflected from the elevation and its surrounding is $\Delta = 2\,tn\cos\theta$

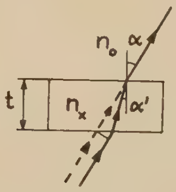

Fig. 2. The transmission interference microscope case. A small disk of thickness t and refractive index $= n_x$, surrounded by a medium of refractive index n_0 retards a transmitting ray (full-drawn line) in respect to a ray outside the object (broken line) with an amount of $\Delta = t(n_x \cos\alpha' - n_0 \cos\alpha)$

In transmission interference microscopes however, which are designed for the measurement of the optical thicknesses of thin transparent objects, interference occurs between two wavefronts without the presence of the object. When an object is inserted into the interferometer system, a measurable shift of the interference pattern is introduced corresponding to the optical thickness of the object. This thickness Δ depends on the incident angle α (Fig. 2) and is given by $\Delta = t(n_x \cos\alpha' - n_0 \cos\alpha)$, and the obliquity correction d to the high numerical aperture is negative.

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L. P. Johansson
C. F. Bruce*

[10 *November*, 1958

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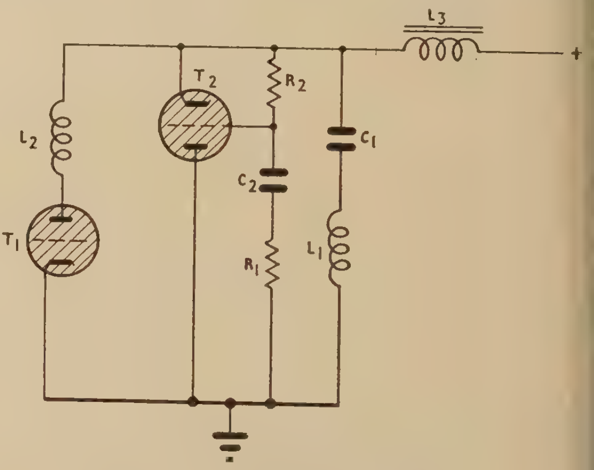
A method of producing eddy-current heating

This method utilizes gas-filled valves instead of vacuum tub In general, gaseous devices are more efficient in that t make use of positive ion space charge to stimulate elect emission.

The circuit is shown in the figure. We start with a posi voltage on the anode of thyratron T_1. When T_1 is trigger one-half period of an LC oscillation occurs, finishing with negative voltage on the anode. The value of this in th absence of losses would be equal to the initial positive voltag This negative voltage is arranged to trigger T_2 automaticall

The next half cycle of the oscillation then takes plac finishing with a positive voltage on the anode of T_1. It i arranged that T_1 has not yet recovered, so that it again strike In this manner a train of damped oscillations passes throug the coil L_1, exciting eddy currents in any system to which i



Typical operating conditions

Pulse repetition rate = 2·9 kc/s; Supply voltage = 5 kV; Input h.t. power = 1 kW; C_1, C_2 = 5000 pF (mycalex), 500 pF; $L = L_1 + L_2 = 4 + 1{\cdot}2\ \mu$H; $L_3 = 7{\cdot}7$ H; $R_1, R_2 = 15\ \Omega$, 10 kΩ; T_1, T_2 = BT 103.

upled. After each train of oscillations the capacitor rly charges through the reactor L_3 to double the supply ge.

th the circuit and supply values shown in the legend of igure, the resonant frequency is approximately 1 Mc/s there are fifteen oscillations in each train. Some of the power (up to perhaps 200 W) is dissipated in the trons, but the serious loss of energy which can arise g to post-pulse heating of the thyratron anode is largely ated by the back-to-back arrangement.

e circuit will function on simple a.c. from a step-up former, dispensing with L_3. Clearly in this case the it only pulses when the supply is positive. This disadvantage could be overcome by triggering the inverse thyratron by means of a high-voltage pulse transformer and, as with the inverse thyratron above, ensuring that the forward thyratron strikes at the end of the first half cycle.

The circuit could be simplified by the use of a tube which would perform the function of both thyratrons, e.g. a thyratron with a second heated cathode as its anode. Acknowledgement is made to Mr. N. S. Nicholls for helpful suggestions and to the Controller of H.M. Stationery Office for permission to publish this note.

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Malvern, Worcestershire

R. J. ARMSTRONG
[18 *December*, 1958]

NOTES AND NEWS

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ucts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

yl ^{14}CD$_3$. Research Specialities Co., 200 South Garrard Boulevard, Richmond, California, U.S.A.

bly labelled L-Methionine (methyl ^{14}CD$_3$) is now available from this firm. Recent reports in the literature indicate this amino acid, labelled with both carbon 14 and erium, is proving useful in studying the mechanism of sterol. The compound is regularly available at a specific ity of one millicurie per millimole, and it is claimed to ree from both chemical and radiochemical impurities. diochromatogram is supplied with each order.

valve voltmeter. E.I.R. Instruments Ltd., 329 Kilburn Lane, London, W.9.

voltmeter is mains driven and is normally scaled as 50 V and 0 to 250 V. The input resistance is of the r of several hundred megohms. It is useful in measuring ges where the circuit resistance is high. The instrument ounted in a case of dimensions 10 × 7 × 6 in.

le graticules. Graticules Ltd., 57/60 Holborn Viaduct, London, E.C.1.

e types of stable graticule are now available, which are pletely resistant to heat, oxidation, humidity and most nicals. A special feature of the surface image type *A* is excessive resistance to abrasion—which, it is claimed, is eat as that of glass itself.

pe *B* is also surface image. It is claimed to be suitable use on optically worked glass blanks, where it gives the est optical characteristics.

pe *C* is cover-glassed; it is stated that the cement is the stable part of these graticules, but as the image face is pletely free from gelatine or colloids, the best possible sion is obtained varying only with the type of adhesive .

ature cam-operated timer. Electrical Remote Control Co. Ltd., Harlow New Town, Essex.

timer consists of a synchronous motor, driving a shaft which there are several cams mounted. These operate ches to make a circuit at one point in the cycle and break another, so giving a controlled time interval.

The following features are claimed by the firm; (*a*) very small overall dimensions; the timer with six changeover switches can be housed inside a space, including $\frac{1}{2}$ in. spindle projection, $6\frac{3}{8} \times 3 \times 3$ in; (*b*) switching capacity 10 A for 250 V a.c. non-inductive; or 6 A for 250 V inductive (in-rush current should not exceed 30 A); and (*c*) every switch has a changeover action.

A friction clutch between the motor and cam shaft is provided and the camshaft spindle projects through one end plate and may be provided with hand resetting to zero position if required. Every timer can be used as a continuously cycling timer, or a hand reset multicircuit multiple-interval timer. The timer can be supplied with the final shaft speed between one revolution in five seconds and one revolution in twenty-eight days.

One of the timer switches can be wired in series with the motor and the cam set to open the motor circuit at a predetermined point during the cycle. The timer can be then used as a hand reset multicircuit multiple-interval timer, as mentioned above. The effective cut-out of every individual cam is continuously adjustable and the setting of one cam in relation to the others can also be adjusted. All the cams are friction mounted on the camshaft.

The timer has end and base mounting facilities, and the shaft is mounted in oil-retaining bearings. The timers normally operate on 440, 230, or 110 V, 50 or 60 c/s, one phase a.c. Step-up or step-down transformers are available for other supplies and a d.c./a.c. conversion unit for operation on d.c.

Mains driven megohmmeter. E.I.R. Instruments Ltd., 329 Kilburn Lane, London, W.9.

This instrument is driven from the a.c. mains. The supply is stabilized to compensate for ±10% change in mains voltage.

The normal range is 1 to 300 MΩ with 10 MΩ at centre scale, this range may be easily modified to suit alternative requirements.

A d.c. volts range is also provided of 0 to 100 V and 20 kV at 250 000 ΩV^{-1}.

The meter has a scale length of approximately $3\frac{3}{4}$ in. and is fitted into a metal case approximately 10 × 7 × 6 in.

Notes and comments

Revised edition of *Notes for authors*

The Institute of Physics has just published a 36-page revised edition of its booklet intended to assist less-experienced authors and to serve as a reference booklet for all those who wish to contribute to the Institute's publications. Under its new title *Notes for authors*, it gives hints on the preparation of scripts and diagrams, on the layout of mathematics, the correction of proofs and so on. In addition to a bibliography of reference books and works on technical writing, the pamphlet also contains lists of the spellings, symbols and abbreviations used by the Institute. These conform with British Standard 1991. Part I: 1954: *Letter symbols, signs and abbreviations, Part I, General* which authors of mathematical papers are also advised to consult.

Authors preparing contributions for submission to this *Journal* are invited to make use of the guidance available in the booklet, copies of which may be obtained from The Institute of Physics, price 3*s.* 6*d.* (including postage).

Electrical instrument test service

The British Scientific Instrument Research Association has established an electrical instrument test service at their laboratories in Chislehurst, Kent. Although originally set up at the request of members of the Association, the service is now available to other firms and organizations.

Operated under the supervision of the National Physical Laboratory and using N.P.L. certified equipment, the department will test and issue certificates for instruments up to precision grade accuracy. Calibration of d.c. meters between 1 mV and 500 V and between 2 μA and 2 A can be undertaken immediately. In the near future the latter range is to be extended up to 25 A and the calibration of a.c. instruments over the ranges 1 V to 500 V and 10 mA–25 A will be undertaken. Charges for the service will be appreciably less than the cost of N.P.L. certification. It is hoped that this service will be welcomed by both manufacturers and users of instruments in this country, particularly where an independent test certificate for an instrument is required, but where the prestige value of an N.P.L. certificate is unnecessary.

Further information may be obtained from The Director of Research, The British Scientific Instrument Research Association, South Hill, Chislehurst, Kent.

1959 Waverley Gold Medal essay competition

This competition, sponsored by the magazine *Research* is designed to draw attention to the problem of communicating scientific information to the layman and also to scientists engaged in other fields.

The Waverley Gold Medal and £100 will be awarded for the best essay of about 3000 words based on some recent scientific research or new development (whether the author's work or not), giving some indication of the scientific background, the experimental results and its potential application in indus
The essays will be judged for technical content, by speciali
in that field, and for clarity of presentation and style.

A second prize of £50 will also be awarded and an additio
prize, also of £50, for the best entry from a competitor un
30 years of age on the 31 July, 1959. The competitio
open only to persons at present in scientific work and
closing date for entries is 31 July, 1959.

Further details may be obtained from the Editor, Rese
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British Journal of Applied Physics

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Notes and comments

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Temperature controller based on measurement of rate-of-change of temperature

By A. B. Cairnie, B.Sc., Ph.D.,* and J. D. Pullar, B.Sc., Ph.D., The Rowett Research Institute,
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[*Paper first received* 17 *June, and in final form* 20 *October*, 1958]

The rate-of-change of temperature of water circulated from a 120 gal tank round the jackets of a direct calorimeter was required never to exceed 0·0005° C/min. Measurement of the rate-of-change of temperature was provided by a gradient layer surrounding a metal block in the tank. A controller was designed to maintain the instantaneous rate-of-change of temperature below 0·0002° C/min, except for a negligible fraction of the time. The mean rate-of-change of temperature is so low that temperature stability to within ± 0·1° C has been obtained for a fortnight. A temperature-controlled room and constant voltage transformer are not required.

equipment to be described has been developed in nexion with a direct calorimeter⁽¹⁾ for animals which s the gradient layer principle to give continuous measure- nt of heat output. This type of calorimeter was devised Benzinger and Kitzinger.⁽²⁾ The accuracy of the instru- nt depends largely on maintaining constant the reference nperature of the gradient layers, that is the temperature of water in jackets which form the walls of the animal mber. These jackets are supplied by pumps from a rage tank in a closed circuit system. To obtain 1% uracy in a one-hour measurement the reference tempera- e must remain constant to ±0·03° C at any temperature hin the range 5–40° C, despite changes in the heat output the animal and variations in room temperature or mains tage.

The most favoured method of accurate temperature control liquids is to use a resistance thermometer or thermistor as arm of an a.c. or d.c. bridge, and to control the heat ut to the bath from the out-of-balance signal. Wilson and ne,⁽³⁾ and Hutchinson, Pulsford and White,⁽⁴⁾ by elaborate cautions, have obtained in this way control of a constant nperature bath to within ±0·001° C.

This type of system is, however, unsuitable for the present pose. Any cycling of the water temperature through the ferential of a thermostatic device would produce undesir- e cycling in the record obtained from the calorimeter. e effect on the calorimeter output becomes significant if rate-of-change of water temperature at any time exceeds 005° C/min. Because of the difficulty of maintaining bility below this level, direct control of rate-of-change of nperature is more attractive than control of temperature lf. The problem is therefore to detect small rates-of- nge of temperature and to make rapid correction for m.

PRINCIPLE OF MEASUREMENT

The rate of flow of heat into or out of a large block of tal immersed in the storage tank is directly related to the e-of-change of water temperature provided mixing is equate. If the block of metal is enclosed within a gradient er an e.m.f. is obtained, the magnitude of which is directly portional to the rate-of-change of water temperature. e polarity indicates whether the water is heating or cooling, d the output may be connected to a galvanometer to provide a very sensitive measure of the rate-of-change of water temperature.

The gradient layer consists of a thin layer of insulation in the path of the heat flow, across which there must be a small temperature difference when heat is flowing between the metal block and the water. A thermopile is constructed with alternate junctions on the inner and outer faces of the layer, so that the total output is the sum of the outputs of individual pairs of junctions. For high sensitivity a large number of junctions per unit area is required.

CONSTRUCTION OF THE MEASUREMENT UNIT

Tufnol strip $\frac{3}{4}$ in. wide by $\frac{1}{32}$ in. thick has been used as the basis of the gradient layer. Short lengths of copper ribbon $\frac{1}{4}$ in. wide by 0·001 in. thick are cut and applied to the Tufnol strip at $\frac{3}{4}$ in. intervals as shown in Fig. 1(*a*). Constantan ribbon $\frac{1}{8}$ in. wide by 0·003 in. thick is then wound over the copper as in Fig. 1(*b*), and the junctions carefully soldered.

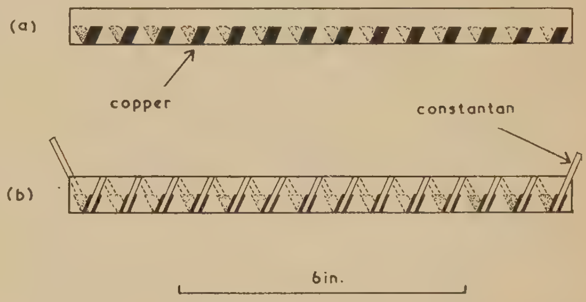

Fig. 1. Method of making thermopile

The aluminium or copper block on which the gradient layer is mounted measures 8 × 24 × 1½ in. Only the two large faces carry gradient layers, the other four faces being well insulated. Neither material nor exact dimensions is important, but the water equivalent should be as large as possible and the surface-to-volume ratio high. The block with gradient layers is enclosed in a close-fitting 22 s.w.g. galvanized iron case with a tube to bring the leads above water level. The internal resistance of the measurement unit is about 35 Ω and it contains approximately 600 pairs of junctions.

Now at Physiology Department, Marischal College, University Aberdeen.

PERFORMANCE OF THE MEASUREMENT UNIT

The storage tank contains immersion heaters, refrigeration coils and the measurement unit. It has a capacity of 120 gal of water which is pumped around the external circuits at 20 gal/min. The return water is used to ensure adequate mixing in the tank. The refrigerator is required for operation near and below ambient temperature. It runs continuously, the excess cooling power being balanced by a Variac-controlled heater. When it is not used in conjunction with the controller described later, the measurement unit is connected to a centre-zero galvanometer and temperature balance is achieved by adjusting the Variac transformer for zero deflexion.

The measurement unit is calibrated by measuring the temperature change over several hours, while constant deflexion is maintained on the galvanometer by adjustment of the Variac. The calibration is linear and independent of the direction of flow. The no-load output is 200 mV $°C^{-1}$ min^{-1}.

The rapidity of response of the system is limited not by the response of the measurement unit but by the speed of heat transfer through the water to the unit. Consequently the position of the measurement unit must be chosen with care. In the present case the requirement is a supply of water to external circuits at constant temperature and not specifically a large tank of water at uniform temperature throughout. By trial and error the most satisfactory results are obtained by positioning the unit near the water outlet.

For other applications the measurement unit could probably be scaled down considerably from the size quoted above. To retain the same sensitivity the number of thermocouples per unit area would have to be increased, but this would present no difficulty, particularly if the copper were deposited on the constantan electrolytically.

PRINCIPLE OF THE CONTROLLER

The measurement unit was initially used with the calorimeter as an indicator to assist in manual adjustment of the Variac to maintain balance. However, changes in ambient temperature and mains voltage produced greater variation in water temperature than could be tolerated. The controller has now been developed to provide fully automatic control for experiments lasting many days. It is still necessary to adjust manually the power fed to the Variac-controlled heater to get within the range of the controller, but th
adjustment is no longer critical.

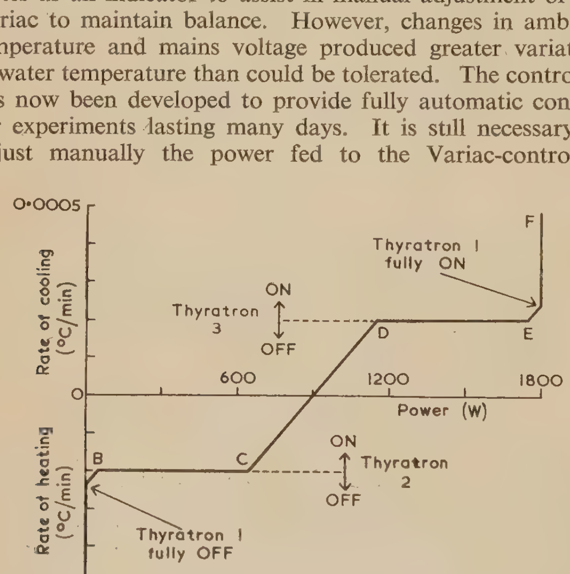

Fig. 2. The response curve *ABCDEF* of the controller. The slope of *CD* is set by the sensitivity control. The intercepts of *CB* and *ED* with the ordinate are preset. The slope, limits and available power shown are those used in the present application. It is a slight simplification to consider *CD* rectilinear

An independent heater is connected in series with
thyratron across the a.c. mains. At balance, with zero inp
to the controller, the thyratron fires at the peak of t
positive half-cycle. Off balance the thyratron fires earlier
later as required to provide correction. Pulse firing
adopted for greater reliability.

To provide extra correction when the rate of heating
cooling exceeds chosen values two further thyratrons, eac
with an independent immersion heater, are used. Unlik
thyratron 1, described above, these thyratrons fire at th
beginning of the positive half-cycle or not at all. Fig.
illustrates the characteristics of the controller. If the rat
of-change of temperature does not exceed the limits chose
the controller acts along *CD*. The slope of *CD* can be varie
If the rate of heating exceeds the pre-set value, thyratron
does not fire and the controller acts along *CBA*. Similarl
if the rate of cooling exceeds the chosen limit, thyratron
fires and the controller acts along *DEF*. In the prese
application both thyratrons are set for 0·0002° C/min, b
the settings are independent.

DESCRIPTION OF THE CIRCUIT

Since it must respond to a d.c. signal from the measurem
unit of about 2 μV from a source with internal resistan
35 Ω, a very sensitive input stage is required in the controlle
Amplification at this level is close to the limit of the b
thermocouple amplifiers described in the literature.(5) A
alternative which has proved very reliable for continu
operation is the Pye galvanometer modulator type 11
which has a 50 c/s a.c. output and a gain of ×1500.

The circuit shown in Fig. 3(*a*) is concerned with the ampl
fication of the signal from the measurement unit and th
production in each cycle of the pulse which controls th
thyratrons. A signal 90° out-of-phase with the main
obtained with a non-inductive capacitor C_5 (type W48,
A. H. Hunt) and a resistor R_9, is amplified by V_{3a}. Th
output of V_{3a} is squared by V_4 and V_5 and differentiated b
C_{10} and R_{19}. Valve V_{3b} acts as a cathode-follower and als
removes most of the negative pulse. The a.c. signal from th
galvanometer modulator, which is in phase or 180° out-of
phase with the mains according to the sign of the d.c. input
is amplified by V_1 and V_2. Hence the phase of the signa
fed to V_4 depends on the output of the measurement uni
and the setting of the sensitivity control RV_1. If the inpu
to V_1 is temporarily shorted by S_1, RV_2 can be adjusted t
bring the leading edge of the positive pulse to the peak o
the positive half-cycle of the mains. The setting of RV
determines the slope of the control characteristic in th
region *CD* in Fig. 2. The phase-sensitive detector V_6 i
used only when setting the zero of the galvanomete
modulator.

The pulse from the cathode of V_{3b} is used directly to fi
thyratron 1, V_7, except that negative bias must be applie
as shown in Fig. 3(*b*) to prevent it firing before the pulse
One of the identical firing circuits used for thyratrons 2 and
is shown in Fig. 3(*c*). The pulse from V_{3b} fires a sma
thyratron V_8, and C_{16} is charged to a voltage dependent o
the time of firing in the positive half-cycle. This voltage i
fed to the grid of a cathode-follower V_{9a} which fixes th
potential of one end of RV_5. The potential of the other en
of RV_5 is determined by the setting of RV_6. From RV_5 i
taken the bias for thyratron 2 or 3, V_{10}. This bias become
more or less negative as the time of firing becomes later o

er in the cycle. Thus, by adjustment of RV_5 and RV_6, large thyratron can be made to conduct during the le positive half-cycle whenever the output of the measure- t unit exceeds a stipulated value. To prevent the critical voltage being exceeded later in the cycle, an a.c. signal out-of-phase with the mains is introduced *via* the grid 9b.

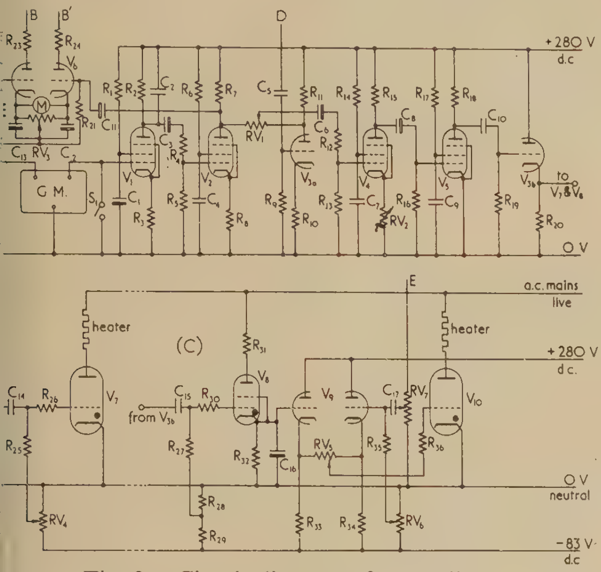

Fig. 3. Circuit diagram of controller

$R_1 = 1$ MΩ
$R_2 = 220$ kΩ
$R_3 = 2{\cdot}2$ kΩ
$R_4 = 220$ kΩ
$R_5 = 1$ MΩ
$R_6 = 470$ kΩ
$R_7 = 100$ kΩ
$R_8 = 4{\cdot}7$ kΩ
$R_9 = 68$ Ω
$R_{10} = 4{\cdot}7$ kΩ
$R_{11} = 100$ kΩ
$R_{12} = 220$ kΩ
$R_{13} = 1$ MΩ
$R_{14} = 470$ kΩ
$R_{15} = 220$ kΩ
$R_{16} = 1$ MΩ
$R_{17} = 470$ kΩ
$R_{18}, R_{19} = 220$ kΩ
$R_{20} = 1$ kΩ
$R_{21}, R_{22} = 470$ kΩ
R_{23}–$R_{25} = 47$ kΩ
$R_{26} = 15$ kΩ
$R_{27} = 470$ kΩ
$R_{28} = 9{\cdot}1$ kΩ
R_{29}–$R_{31} = 100$ kΩ
$R_{32} = 47$ kΩ
$R_{33}, R_{34} = 100$ kΩ
$R_{35} = 470$ kΩ
$R_{36} = 15$ kΩ
All resistors are ½ W ± 10%

$RV_1, RV_2 = 250$ kΩ
$RV_3 = 100$ kΩ

$RV_4 = 25$ kΩ
$RV_5 = 250$ kΩ
$RV_6, RV_7 = 25$ kΩ
All variable resistors are carbon

$C_1 = 2$ μF, 350 V
$C_2 = 0{\cdot}01$ μF
$C_3 = 1$ μF, 350 V
$C_4 = 0{\cdot}1$ μF
$C_5 = 2$ μF, 150 V, metallized paper
$C_6 = 1$ μF, 350 V
$C_7 = 0{\cdot}1$ μF
$C_8 = 1$ μF, 350 V
$C_9 = 0{\cdot}1$ μF
$C_{10} = 0{\cdot}01$ μF
$C_{11} = 2$ μF, 350 V
$C_{12}, C_{13} = 50$ μF, 50 V
$C_{14} = 0{\cdot}1$ μF
$C_{15} = 0{\cdot}02$ μF
$C_{16} = 8$ μF, 350 V
$C_{17} = 0{\cdot}1$ μF

V_1, V_2 = EF86
V_3 = ECC81
V_4, V_5 = EF86
V_6 = ECC81
V_7 = XG1/2500
V_8 = EN91
V_9 = ECC81
V_{10} = XG1/2500
(All valves by Mullard)

4′, input from measurement unit; *BB*′, independent 100 V :. winding; *D*, 100 V a.c. winding in phase with the mains ie other connexion to neutral); *E*, 100 V a.c. winding out-of- iase with the mains (the other connexion to neutral); *G.M.*, e galvanometer modulator type 11 351; *M*, centre-zero meter.

he stabilized d.c. power supplies are standard. Absence ipple in the positive line is important and a series valve d.c. amplifier is advisable. The negative line is supplied simple neon stabilizer.

he type of thyratron is chosen in relation to the cathode ent required. In the present case the variation in heat irement is approximately 200 W. The Mullard type 1/2500 thyratron, which has a rating of 2·5 A, is therefore , giving 600 W in the associated heater when firing at beginning of the half-cycle. No alteration to the circuit quired when other types of thyratron are used.

PERFORMANCE OF THE CONTROLLER

Hutchinson, Pulsford and White(4) pointed out the difficulties of measuring the short-term behaviour of an accurate temperature control system. In the present case the most obvious method is to study the error in the output of the calorimeter gradient layers. This was found to be within tolerance. The long-term performance can be assessed using a Beckmann thermometer to measure temperature changes with an accuracy of ±0·005° C.

(*a*) *Variac-controlled heater correctly set.* With the Variac correctly set the power developed fluctuates mainly within the region *CD* in Fig. 2. In a trial lasting 17 h the rate-of-change of temperature exceeded 0·0002° C/min for only seven very short periods. In one test with the water at 20° C the temperature increased in the first 4 h by 0·02° C and fell 0·03° C during the next 17 h. At 35° C, on another occasion, there was no detectable change in the first 12 h, but in the next 12 h the temperature fell by 0·04° C and again in the final 12 h by 0·02° C.

(*b*) *Variac-controlled heater incorrectly set.* The value of the controller lies in the fact that the Variac need not be precisely set to keep the rate-of-change of temperature small. Fig. 4 shows the relation between the mean rate-of-change of temperature, measured using the Beckmann thermometer, and the error in setting the Variac expressed as watts off balance. A mean rate-of-change of temperature of 0·0002° C/min corresponds to ±20 W off balance without the controller and ±500 W when the controller is used.

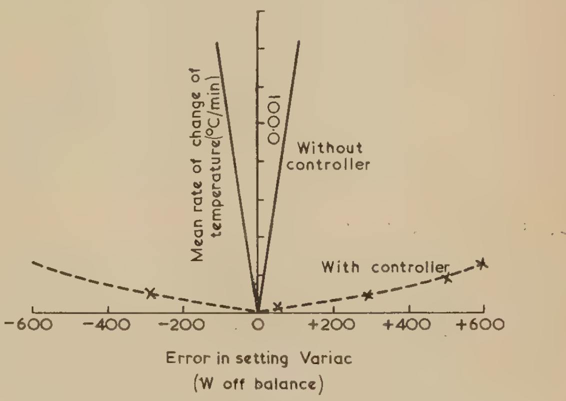

Fig. 4. Performance of the controller

As the Variac is moved away from the balance position, although the mean rate-of-change of temperature remains small, the instantaneous value cycles over a wider range owing to the correcting action of the controller. For an increasing fraction of the time, the rate-of-change of temperature exceeds 0·0002° C/min. At +200 W off balance the thyratron current, measured with a recording ammeter, cycles with a period of 3 min from a low rate of cooling to a rate of heating exceeding 0·0002° C/min. At +600 W the rate of heating drops below 0·0002° C/min for only a small fraction of the time.

CONCLUSION

The accuracy of the controller is affected only by the setting of the galvanometer modulator zero which is checked every few days. One instrument has been in use for over a year and has proved reliable and trouble-free. In a typical experiment lasting a fortnight the water temperature variation was less than ±0·1° C.

In the present application changes of water temperature are often necessary. After a rapid change to the required temperature the heat input is adjusted by experience to approximately the correct value and the controller put into operation. Temperature stability to within ±0·0002° C/min is obtained in less than half an hour.

The controller is suitable for application to a wide variety of problems. It could be used to provide a steady rate-of-change of temperature, either by suitably off-setting the zero adjustment or by connecting a low impedance microvolt source in series with the measurement unit. This source could be calibrated directly in rates-of-change for applicati requiring complex programmes of heating and cooling.

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The epitasimeter: An instrument for process control by means of th continuous measurement of surface tension

By W. H. Aarts, M.Sc., Ph.D., Research Department, African Explosives and Chemical Industries Limited, Northrand, Transvaal

[*Paper first received* 26 *August, and in final form* 23 *October*, 1958]

Physical methods of determining chemical concentrations are very useful in the control of process plants. While many physical properties have been so used, little use seems to have been made of surface tension.

Surface tension measurements are frequently used in the laboratory, and generally an absolute value of the surface tension is required. For process control, however, absolute measurements are often not essential. The method described here uses a jet of liquid issuing from an elliptical orifice to form a standing wave. Viscosity effects are either eliminated or allowed for in the temperature compensating circuits.

INTRODUCTION

There are numerous static and dynamic methods of determining surface tension. Dynamic methods are to be preferred in certain circumstances because a new surface is continuously being formed. This eliminates the effects of contamination by the surrounding media and in the case of surface active agents such as "Lissapol," their molecules do not have a sufficiently long period of time to migrate to the surface and hence effect the surface tension. While most of the static methods are well known, dynamical methods involving for example oscillating jets or water bells,(1) have rarely been used to obtain absolute values of surface tension because too many different and difficult measurements have to be made to give accurate values. Bohr(2) showed, however, that these difficulties of a dynamic method could be overcome and that the complex case of an oscillating jet could give accurate absolute values of surface tension provided that sufficient skill was applied to the problem. There is no better way of illustrating this point than by considering the equation derived by Bohr for the surface tension of a jet of liquid issuing from an "elliptical" orifice, viz.:—

$$\gamma = \frac{2\pi(\delta+\rho)r^3U^2J_2(2\pi ir/\lambda)}{(3+4\pi^2r^2/\lambda^2)ir\lambda J_2'(2\pi ir/\lambda)} \times \left[1+2\left(\frac{\eta\lambda}{\pi\rho Ur^2}\right)^{3/2}+3\left(\frac{\eta\lambda}{\pi\rho Ur^2}\right)^2\right] \times \left(1+\frac{37b^2}{24r^2}\right)$$

where γ = the surface tension of the liquid
ρ = the density of the liquid of the jet
δ = the density of the surrounding medium
r = the "radius" of the jet

$$= \frac{1}{2}(r_{max}+r_{min})\left(1-\frac{1}{6}\frac{b^2}{r^2}\right)$$

where $\dfrac{b}{r} = \dfrac{r_{max}-r_{min}}{r_{max}+r_{min}}$

U = average velocity of the jet over the distance which measurements are made
$J_2(x)$, $J_2'(x)$ = second order Bessel function and its derivati
$i = \sqrt{-1}$
λ = wavelength of the oscillation
η = the viscosity of the liquid.

For liquids of low viscosity, ($\eta < 0{\cdot}01$ P) the second ter of the expression approximates to unity and on expanding the Bessel functions

$$\gamma = \frac{4\pi^2(\delta+\rho)U^2r^3\left(1+\frac{37}{24}\frac{b^2}{r^2}\right)}{\lambda^2[6+10(\pi r/\lambda)^2+2{\cdot}5(\pi r/\lambda)^4]}$$

This simplified expression is still quite formidable. Oth dynamical methods also suffer from the same difficulties that numerous measurements have to be made so that th necessary numerical data can be substituted in a complicat formula.

For the purpose of process control, however, absolu determinations are not necessary because, for example, th apparatus may be empirically calibrated in terms of th parameter which is to be measured.

In deriving the formula for waves of small amplitude Bo made certain assumptions, one of which was that the initi disturbances caused by the ejection of the liquid from th orifice were absent in the portion of the jet being measured

VISCOSITY EFFECTS

/hen a fluid flows through a narrow tube in streamline the velocity at the centre of the tube is considerably ter than that near the wall. When the liquid leaves the to form a jet the viscosity of the fluid therefore gives to an acceleration of the outer layers relative to the ral core, until at equilibrium, the whole jet moves forward uniform velocity.

iscosity is a function of temperature. In the case of er at ordinary temperatures a rise in temperature of 1° C luces a 3% lowering of its viscosity. The initial velocity he axial part of a jet emitted from a tube of circular crossion (radius, r) is given by

$$v = \frac{P}{4l\eta}r^2$$

re P is the pressure applied to force the liquid through tube and l is the length of the tube. Therefore, for water, C change of temperature will produce a 3% change in v. iscosity will in general vary with the concentration of a tion. Consequently, direct compensation for temperature viscosity in the case of the process control of the centrations of solutions, will be complicated.

he above effects of viscosity can be considerably reduced nstead of a tube or nozzle, we make use of a knife-edged ce to form the jet because, in this manner, the viscous at the outside edges of the jet is minimized. If the jet es from a vessel of large volume we have, by Torricelli's rem, the following expression for its initial velocity: $= 2gh$, where h is the height of the free surface of the id above the orifice and g is the acceleration of gravity. is kept constant, then for any particular orifice Bohr's nula reduces to

$$\gamma/\rho = \frac{K}{\lambda^2[6 + 10(\pi r/\lambda)^2]}$$

the case where $\delta \ll \rho$ and $r \ll \lambda$. K is a constant. may therefore be empirically measured in terms of the gnitude of the only remaining variable, λ, the wavelength he oscillation.

ohr made use of the fact that an oscillating liquid jet f forms a system of lenses and curved mirrors. He illuated a jet with a beam of light and carried out his measurets on the reflected light. This system works well provided e is a reasonably good reflecting surface and no gas or our present which can absorb an appreciable amount of light. The method of Stocker,(4) in which transmitted t is used, is more satisfactory when these interferences, ticularly the latter one, are present.

THE EPITASIMETER*

n oscillating jet can be said to consist of a series of lenses. refracting surfaces of the lenses have two curvatures and jet therefore forms a continuous chain of symmetrical stigmatic lenses (Fig. 1). One of the double convexovex lenses is chosen in the epitasimeter for locating the ition of one wave. Fig. 1 shows how an incident parallel m of light is focused and forms the series of lines F_1, F_2 F_3 normal to the plane of the paper. Fig. 2(*a*) shows a single wave in section. Fig. 2(*b*) shows, on the same e, a plan of the optical system which illustrates how the em also focuses the light along the line f, between the and F. The location of a particular standing wave has been carried out automatically by using three photomultiplier tubes, mounted in a servo-controlled carriage.(5) Two prisms (Fig. 3) are placed a small distance apart. If the light falls on the upper prism, the detector PM_1 is illuminated and a signal is generated to move the carriage upwards. If the light falls on the lower prism and PM_2 is illuminated the servo-motor moves the carriage downwards. If light falls between the prisms, photo-multiplier tube PM_3 closes a relay which operates a lamp to indicate that the carriage is in the equilibrium position and is correctly measuring the position of the standing wave.

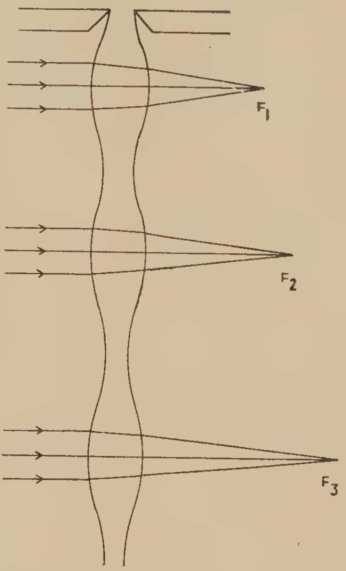

Fig. 1. The formation of different line images normal to the plane of the paper at F_1, F_2, F_3

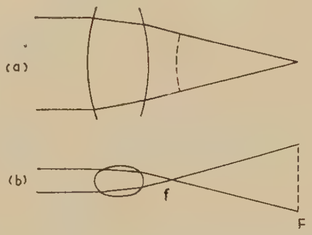

Fig. 2. The paths of the light rays forming another image at f

The image at f lies in the same plane as the jet.

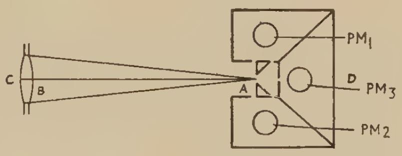

Fig. 3. Automatic location of standing wave

Light is refracted by the lens surfaces C and B so as to focus at A. The positions of the three photo-multiplier tubes PM_1, PM_2, PM_3, in their compartments are shown relative to the two prisms in the image locator D.

The position of the image-locating carriage is measured in terms of the position of a drum potentiometer driven by the same shaft as that which raises and lowers the carriage. This potentiometer P_1 forms part of a Wheatstone bridge, as shown in Fig. 4. The resistor R_1 is a resistance thermometer included in the circuit to allow for changes in surface tension due to changes in temperature.

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* From the Greek, επι = upon and τασις = tension.

The ratio γ/ρ is a function of temperature and hence the distance, x of the image locator below the orifice will be a function of the temperature for any given concentration. A temperature coefficient α of x can be defined as follows:—

$x_T = x_{15}[1 - \alpha(T - 15)]$ where x_{15} and x_T are the distances respectively at 15 and T° C. If α is a constant the potentiometer P_2 in Fig. 4 can be wound with a low resistance copper wire or it can in fact be eliminated. However, if α is not quite a constant and it varies slightly with temperature and concentration this can be allowed for by making P_2 of various sections of high conductivity and resistance wire. P_1 is the potentiometer which indicates the position of the moving carriage on the galvanometer of the Wheatstone bridge, while the platinum resistance thermometer corrects the resulting galvanometer movement for the effects of temperature. P_2 is constructed so that the effects of the platinum resistance thermometer are not the same for all positions of the moving carriage. For example in the case of very strong nitric acid the effects of temperature changes on the position of the image locator are greater for low temperatures than for high temperatures. At low temperatures the surface tension is high and therefore the standing wave will be high as well, and hence the image locator will also be high. The corresponding section of P_2 therefore has some resistance wire so that the resistance in series with the platinum wire is reduced at this end of the movement thereby increasing the effect of the platinum thermometer. As sufficiently accurate values of the variation of surface tension with temperature are in general not known the simplest method of determining the resistance sections of P_2 is by visual observation with a travelling microscope on any particular wave. Variation of temperature and concentration can then give the variation of α and hence the resistance sections of P_2 can be calculated so as to eliminate the effects of temperature changes completely.

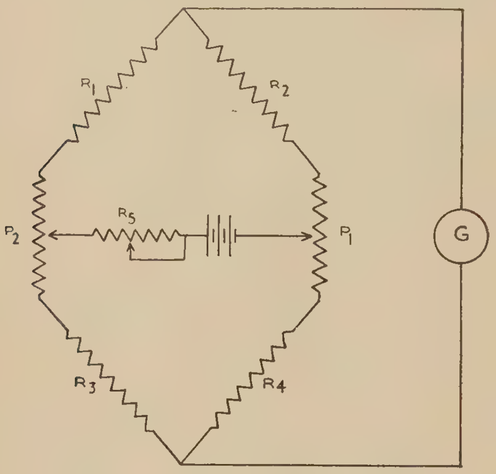

Fig. 4. The Wheatstone bridge

R_1 is the resistance thermometer immersed in the liquid. P_1 is the potentiometer which indicates the position of the image locator. P_2 is the potentiometer made of two metals to allow for changes in temperature coefficient of viscosity with changes in concentration.

$R_1 = 120\,\Omega$, $P_1 = 10$ turns of manganin wire wound on a drum of 12 cm diam. P_2 is a low resistance copper winding on the same drum with $1{\cdot}6\,\Omega$ (60 cm) of manganin wire in series with R_1. G is a 2000 Ω 25–0–25 microammeter

The instrument can be made to indicate the concentrati of the solution directly. This adjustment can be made f any desired range of concentration by adjusting the instr ment in the manner described hereafter.

Liquid of the desired concentration is allowed to flo through the elliptical orifice from a vessel in which the fr surface of the liquid is maintained at a constant level. T image locator is then set manually on the image focused the desired standing wave. The Wheatstone bridge is th balanced by rotating the drum potentiometer while it is n coupled to the image locator. The image locator and dru potentiometer are then coupled together and the serv control permitted to come into operation. The next adjus ment is the span of the instrument. Liquid of the highe (or lowest) concentration expected is run through th apparatus and when the image locator is at its highest (lowest) position the resistor R_5 is adjusted to give a full sca deflection on the galvanometer. The general arrangement shown in Fig. 5.

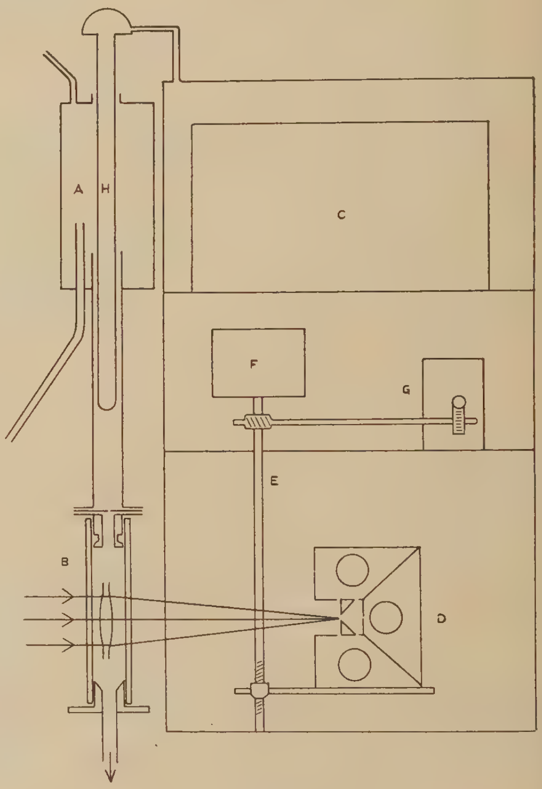

Fig. 5. The epitasimeter

A is the constant level supply vessel. B the jet chamber, C the power supply and amplifiers, D the image locator, E the image locator raising and lowering screw, F the drum potentiometer, G the servo-motor and H the resistance thermometer well. The orifice finally selected for use with strong nitric acid was an ellipse of major axis $2{\cdot}12$ mm and minor axis $1{\cdot}57$ mm. The servomotor used was a two-phase 110 V 1/40 h.p. recorder balancing motor. The reduction gearing consisted of two worm wheels giving a velocity ratio of 3600 to 1. The pitch of the raising screw was 1 mm.

Instead of using an electrical method of indicating th image locator position, pneumatic or mechanical method can be used. An electrical method is preferred however a it makes both remote indication and temperature com pensation easier.

In the case of a liquid such as nitric acid giving off noxiou nes self cleaning windows must be fitted. Half of the jet mber and window system is shown in Fig. 6.

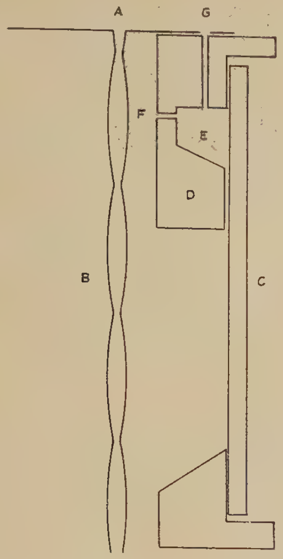

Fig. 6. Prevention of the formation of drops on the inside of the window when windows are necessary

G is a capillary leading to a small chamber *E* with an overflow F. Part of the frame *D* is recessed for a few thousandths of an nch with the result that a thin flat film of liquid runs down the inside of the glass *C*. *A B* is the jet.

CONCLUSION

The instrument was originally developed to measure the ncentration of a very concentrated nitric acid containing 1 to 2·0% nitrous acid and 1 to 7% water. Such acids e usually analysed titrimetrically by using standard alkali determine the total acid concentration. The nitrous acid ncentration is determined by titration with standard tassium permanganate and the nitric acid concentration lculated by difference. This method of determining nitric id concentration is lengthy and several attempts have been ade to devise a physical alternative for the titrimetric ethod. Unfortunately the varying amounts of nitrous id, nitrogen oxides and water caused methods based upon easurements of density, electrical conductivity, etc., to give nbiguous results.

The accompanying graph (Fig. 7) shows the almost linear lationship established between the position of a particular anding wave in the epitasimeter and the concentration of e nitric acid.

The instrument measures the ratio of surface tension to nsity. These two parameters are functions of concentra- on. In some instances, for example the case of brine lutions, the two functions are so similar that the ratio, $/\rho$ remains practically constant for different concentrations ıd the method is quite unsuitable. In the case of current terest, however, water increases the surface tension and creases the density of the nitric acid while the oxides of trogen appear to have the same effect as water on the tio γ/ρ. The instrument can therefore measure the con- ntration of very strong nitric acid directly. Another stem to which the method can be successfully applied is at of ethanol/water. If the concentration of ethanol in ater increases from 0 to 5·2% the change in γ/ρ is from 72·3 to 55·4 dyn/cm × g × cc. Using an orifice of $r = 1$ mm and a wavelength of 2 cm a change of concentration of $\frac{1}{8}$% can be determined as this gives a movement of the image locator of 0·25 mm. With a different orifice and a large wave number even greater accuracy would be obtained provided the temperature coefficient of displacement of the wave were known sufficiently accurately. On the other hand, at other concentrations, conditions might well be less favourable. The relative reduction in surface tension due to the increase of alcohol concentration is much greater than the reduction in density and therefore there is a marked decrease in γ/ρ with increasing concentrations of alcohol.

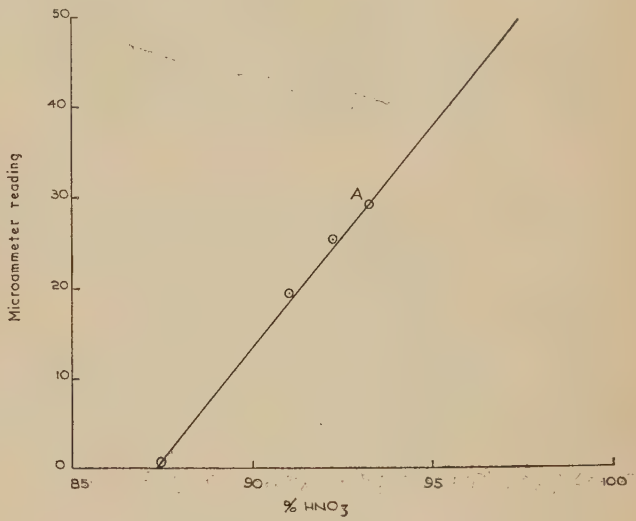

Fig. 7. Relation between the galvanometer readings and the nitric acid concentration

The slope of the line is determined by the span setting, in the above case in an earlier experiment. The position of the solid line is obtained from the instrument zero setting, in the above case on the point *A*. The mean 99% C.I. for the chemical analyses is 0·05% and for the instrumental analyses the 99% C.I. is 0·03% nitric acid.

ACKNOWLEDGEMENTS

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These instruments have been the subjects of patent applications.

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Apparatus for measuring the spreading coefficient of a liquid on a solid surface*

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[*Paper first received* 31 *October*, 1958, *and in final form* 23 *January*, 1959]

The apparatus described provides a direct-reading instrument for the measurement of the spreading coefficient of a liquid on a solid surface. The determination is based on the measurement of the maximum height of a sessile drop of the liquid-solid system.

The spreading coefficient(1) may be described as a measure of the tendency of a liquid to spread on its substratum. For a liquid spreading on a solid substrate, the spreading coefficient S_c is given by

$$S_c = \pi_S - \pi_I - \gamma_L \qquad (1)$$

where π_S, π_I and γ_L are the surface energies of the solid-air, solid-liquid and liquid-air interfaces, respectively. For a non-spreading system, S_c possesses a negative value and for such conditions sessile drops of liquids will form.

It has been shown(2) that such a sessile drop, when successively increased in volume, reaches some constant maximum height (h) for a given solid-liquid system, providing the system is aged to reach equilibrium. It has also been shown that this maximum height is related to the spreading coefficient by:

$$S_c = -\frac{\rho g h^2}{2} \qquad (2)$$

where ρ is the density of the liquid and g is the gravitational acceleration.

The apparatus described uses this principle to measure the spreading coefficient directly. It is obviously preferable to the standard method, which uses the contact angle θ, where:

$$S_c = \gamma_L (\cos\theta - 1) \qquad (3)$$

because the measurement of contact angle is tedious, slow, and is not suitable for systems affected by ageing (water on paper or photographic materials, for example).

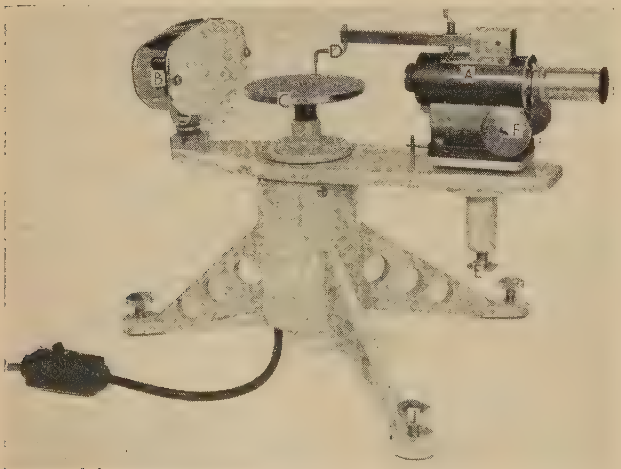

Fig. 1. Apparatus for measuring spreading coefficient

The apparatus shown in Fig. 1 provides essentially a method of viewing the profile of a sessile drop against a suitable graticule. A standard microscope unit (A), fitte with a graticule graduated in ergs per square centimetr (units of spreading coefficient), is used to view the sessil drop system which is illuminated from the rear by a diffus source of light (B). The solid surface, with its sessile dro rests on the sample platform (C), the height of which can b adjusted.

The microscope is fitted with a 3 in. (×1·7) objective a a ×7·5 Huygenian eyepiece, and an adjustable pointer (enables the position of a surface to be detected accurate The microscope unit is raised or lowered by the adjustment is moved to and fro by the adjustment F, and rotates abou its supporting rod.

The inverted image of the sessile drop made it necessary t use a graticule of the form shown in Fig. 2. It is graduate according to equation 2, where the spreading liquid is assume to be water of density 1 g ml.$^{-1}$.

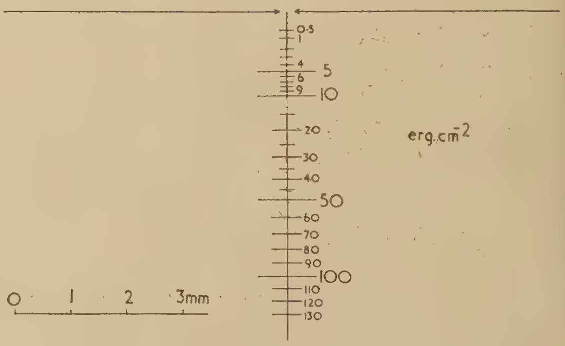

Fig. 2. Diagram of graticule

The magnification of the instrument is set at the appro priate value by viewing a steel ball of known size an adjusting the draw tube so that the image of the ball corresponds to a value calculated from its diameter. The draw tube is then locked in position. The apparatus can then be used for all measurements with liquids of density 1 g ml.$^{-1}$ For liquids of different density, the magnification can be altered with the same graticule, or another graticule may be used.

A few elementary precautions need to be followed. A dirty atmosphere must be avoided, as dirt and organic vapours tend to contaminate the interfaces. A plastic envelope over the whole platform is sometimes necessary to prevent evaporation of a volatile spreading liquid. The sample on which measurement is to be made should be level.

Any sessile drop will give an *apparent* spreading coefficient when viewed with this apparatus. The *apparent* spreading coefficient is equal to the *real* spreading coefficient only when the sessile drop reaches its maximum height, a condition obtained when the addition of a further $\frac{1}{2}$ ml. of liquid to drop produces no further change, within ±2%. All ems measured had reached their maximum drop height n the diameter of the drop was 2 cm.

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* Communication No. 1982H from the Kodak Research Laboratories.

on-wetting systems require more liquid than wetting ems because of their greater height. However, 1·5 ml. liquid was found sufficient to ensure maximum drop ht under all conditions. Calculations from the results of nforth and Adams(3) tend to confirm that this volume uld be sufficient to ensure maximum drop height when capillary constant ($2\gamma/\rho g$) is equal or less than 0·146 cm^2, is, all conditions likely at room temperature.

ccasionally the apparent spreading coefficient increases n time, the drop appearing to spread slowly outwards on solid surface without coming to equilibrium immediately. s effect has usually been found to be the result of the solid contaminating the liquid-air interface, thereby reducing its surface tension.

The main virtues of the apparatus are that it is direct reading and simple to operate. Further details of construction will be supplied on request.

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Homodyne detector for reproduction of periodic wave forms

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[*Paper first received* 5 *November, and in final form* 16 *December*, 1958]

The principle of homodyne detection is applied to a method of reproducing periodic wave forms in the audio-frequency range on a pen recorder. The signal is fed to a gate, which is opened by a short reference impulse. The time position of the reference is swept over the signal cycle by aid of a linear phase-shifter, so that all points on the signal curve are consecutively and individually recorded when passed through the gate to an r.c.-filter and finally to the recorder.

INTRODUCTION

advantage of homodyne detection for improving the nal-to-noise ratio has for a considerable time been utilized various measuring systems, where a reference voltage of iciently high level is obtainable with constant phase tion to the signal. If the sine or square wave reference eplaced by an impulse of short duration, and if the phase this impulse is made variable at will, it would be possible elect a certain part of a repeated signal cycle for recording.

us now assume that the phase position of the reference ulse is slowly swept over the whole signal cycle by some t of phase displacement device. The amplitudes of all nts on the signal curve are by these means consecutively l individually recorded when passed through a gate opened the reference impulse, and then applied to an r.c. filter l finally to a pen recorder. If the period of the sweep over individual signal cycle is properly dimensioned in relation the time constant of the filter circuit and the recorder, we ll obtain a true reproduction of the signal curve on the order tape.

rimarily intended for tracing the absorption curve in an ctron spin resonance spectrometer, the impulse scanning nodyne detector described in this paper may be of some eral interest for recording the shape of a repetitive signal the audio-frequency range with improved signal-to-noise o. Subsequent to the completion of this work, however, re appeared a paper by Hertz and Möller(1) describing an aratus for reproduction of periodic wave forms based on ystem somewhat different from our device.

DESCRIPTION OF THE APPARATUS

block diagram of the apparatus is shown in Fig. 1, and complete circuit is indicated in Fig. 2. A sine wave illator was used as a common source for signal and rence. The reference impulses were brought to sweep over the signal cycle in the following manner. The phase of the sine wave reference was shifted linearly with time by aid of a synchro-resolver. The circuit used was almost identical with that described by Sayre.(2) The shaft of the resolver rotor was made to revolve by a small synchronous motor equipped with a speed gear reducer, so that the shaft rotation was 0·20 rev/min. The phase shifted sine wave was then used for triggering a simple impulse generator, tubes T_{10}, T_9, T_7 and T_6.

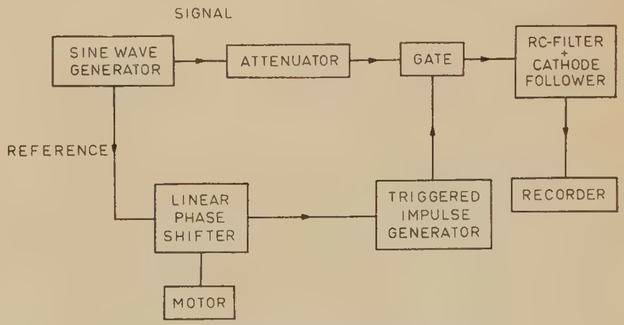

Fig. 1. Block diagram of the experimental arrangement for reproduction of a sine wave

The gate is a modification of a circuit described by Sach and Oliner.(3) The signal is split into two opposite phases by the inverter stage, tube T_1, and then applied to the grids of a differential amplifier, tubes T_2 and T_3. When no reference impulses are present, T_2 and T_3 are non-conducting, and the gate is closed due to the high positive potential applied to the cathodes in relation to the grids to which the proper bias is supplied by a voltage divider. The high potential is due to the current flowing through the common cathode resistor R_1 from tube T_4. The reference voltage is applied to the grid of T_4 in form of a negative impulse (about 40 V), thus

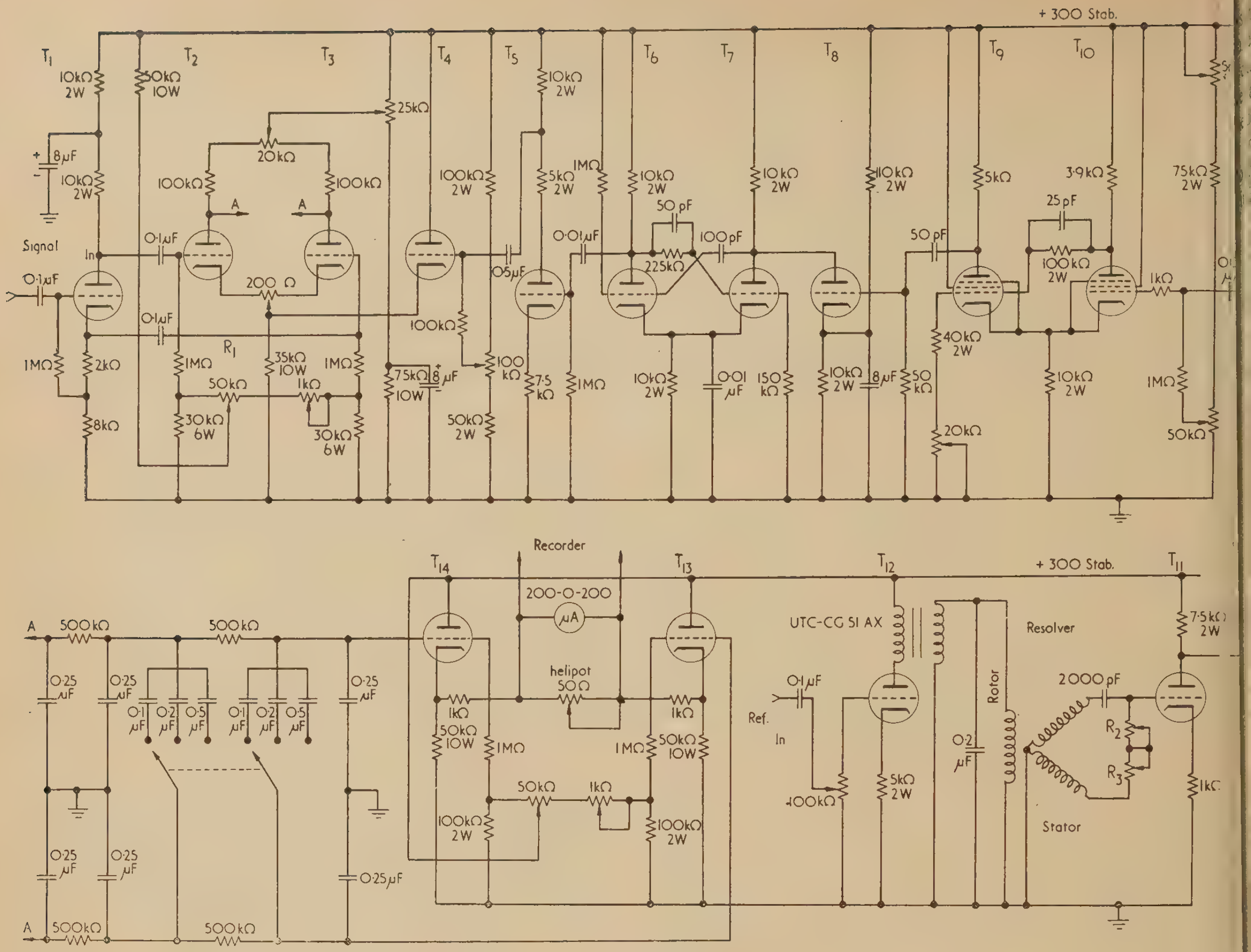
+ 300 Stab.
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
10kΩ 2W
50kΩ 10W
25kΩ
10kΩ 2W
20kΩ
8μF
10kΩ 2W
100kΩ
100kΩ
A
A
100kΩ 2W
1MΩ
5kΩ 2W
10kΩ 2W
50 pF
10 kΩ 2W
110kΩ 2W
5kΩ
3·9kΩ
25pF
75kΩ 2W
Signal
In
0·1μF
0·1μF
0·01μF
100pF
225kΩ
50 pF
100kΩ 2W
1kΩ
200 Ω
0·5μF
0·1μF
100kΩ
40kΩ 2W
1MΩ
2kΩ
1MΩ
R1
35kΩ 10W
1MΩ
50kΩ
1kΩ
75kΩ 10W
8μF
100 kΩ
7·5 kΩ
1MΩ
10kΩ 2W
0·01 μF
150 kΩ
10kΩ 2W
8μF
50 kΩ
10kΩ 2W
1MΩ
8kΩ
30kΩ 6W
30kΩ 6W
50kΩ 2W
20kΩ
50kΩ
Recorder
T14
T13
T12
+ 300 Stab.
T11
200-0-200
μA
A
500kΩ
500kΩ
UTC-CG 51 AX
7·5kΩ 2W
Resolver
0·25 μF
0·25 μF
0·25 μF
0·1 μF
0·2 μF
0·5 μF
0·1 μF
0·2 μF
0·5 μF
helipot 50Ω
1kΩ
1kΩ
0·1μF
Rotor
2000pF
Ref.
In
50kΩ 10W
1MΩ
1MΩ
50kΩ 10W
0·2 μF
R2
R3
50kΩ
1kΩ
400kΩ
5kΩ 2W
1kΩ
100kΩ 2W
100kΩ 2W
Stator
0·25 μF
0·25 μF
0·25μF
A
500kΩ
500kΩ

Fig. 2. Schematic diagram of the impulse-scanning homodyne detector

T_1, T_4, T_5, T_6, T_7, T_8, T_{11}, T_{12}, T_{13}, T_{14} = $\frac{1}{2}$ 6SN7; T_2, T_3 = $\frac{1}{2}$ 6SL7; T_9, T_{10} = 6AC7; $R_1 = 35\ \text{k}\Omega$; $R_2 = 100\ \text{k}\Omega$; $R_3 = 3\ \text{k}\Omega$ (fine adjustment). All fixed resistors are 1 W if not otherwise specified; potentiometers and adjustable resistors are 4 W; if not otherwise stated capacitances are given in microfarads.

causing the current through the tube to be cut off. The cathode voltages of the differential amplifier are now returned to their normal operating values, and the gate is opened. The output from the differential amplifier gate is directly applied to the filtering circuit and to the grids of the cathode follower output stage, tubes T_{13} and T_{14}. The voltage appearing across the Helipot resistor is fed to a pen recorder.

Being almost insensitive even to large variations of the amplitude of the reference impulses, this detector has proved to be very reliable and stable. For proper operation, it is essential that the direct current potential of the anodes of tubes T_2 and T_3 and those of the cathode follower grids, tubes T_{13} and T_{14}, are adjusted, so that only a minimum of current flows through the filter resistor to the grids in the absence of a signal. The circuit parameters of both halves of the differential amplifier gate and of the cathode follower respectively must be adjusted, so that the static potentials are properly symmetrical.

PERFORMANCE TESTS

A frequency of 1000 c/s was used in all experiments. Although no attempts were made to find the upper frequency limit for proper operation, the increasing impedance of the iron-core windings of the resolver seems to become a limitin factor of the first order.

Fig. 3 shows the recorded curve of a sine wave signal 0·5 V amplitude. The duration of the reference impulse was 20 μs. The linearity of the apparatus was tested wit sine waves in the input range between 0·1 to 0·5 V. Th

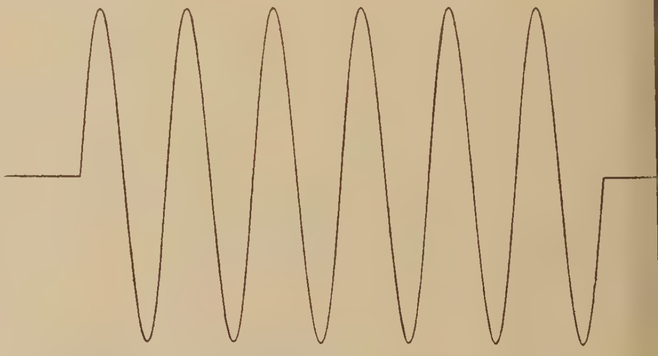

Fig. 3. Reproduction of a sine wave signal

Frequency = 1000 c/s; input voltage to the detector = 0·5 V; duration of the reference impulses = 20 μs; speed of the recorder paper = ¼ in./min.

ult is shown in Fig. 4. When the recorder pen had just sed the zero-line level after having traced a complete e, the signal level was changed by turning a calibrated attenuator, connected up between the sine oscillator and detector, to a new position. It is evident that the response inear within ±1% in the range tested, and that the itive and negative deflexions are of the same amplitude nin ±2%.

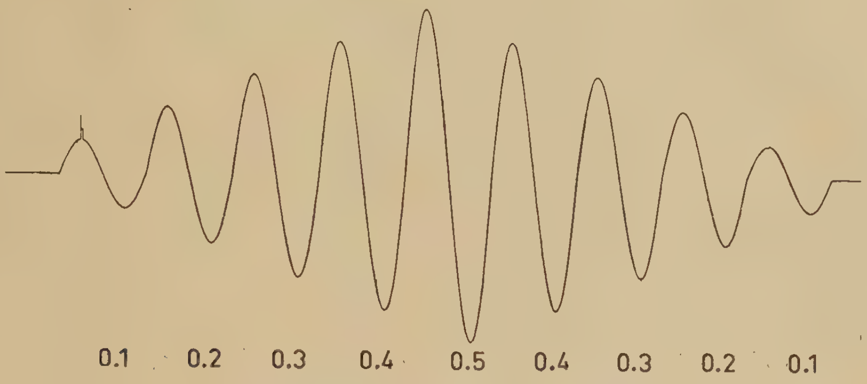

Fig. 4. Test for linear response of the detector

Frequency of sine wave signal = 1000 c/s; duration of the reference impulses = 20 μs; speed of the recorder paper = ¼ in./min; the figures indicate input voltage.

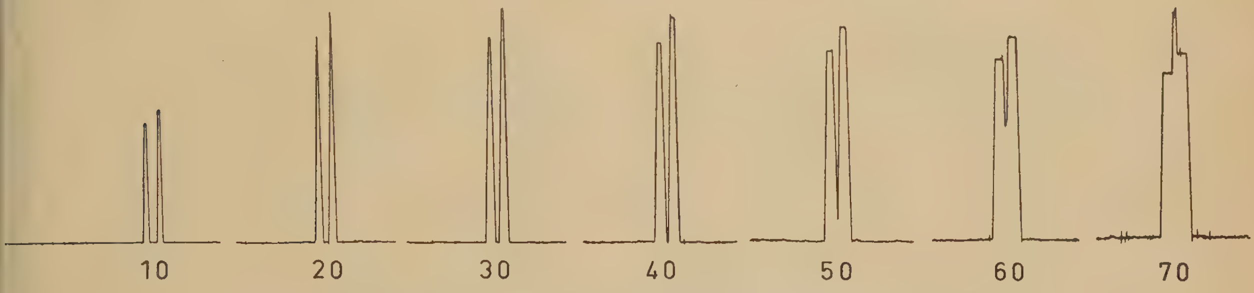

Fig. 5. Resolution of a double impulse signal of positive polarity

Repetition frequency = 1000 c/s; duration of each impulse and of the interval time = 20 μs (approx.); speed of the recorder paper = ½ in./min; the figures indicate the duration of the reference impulses in microseconds.

n order to test the resolving power, a double-impulse nal was fed to the detector from a generator triggered by sine reference. The effect of reference impulses of varying gth on the resolution of an equally spaced double-impulse shown in Fig. 5. The duration of both signal impulses is μs, and the interval between them is also about 20 μs. e duration of the reference impulses has been varied from to 70 μs. From the records it is evident that reference pulses of longer duration than that of the signal impulses e rise to an incorrect length of the signal recorded. As a tter of fact the impulse length recorded is now that of the erence instead of that of the signal. With increasing length the references, the double-impulse signal merges into one ge unresolved impulse.

he amplitude of the recorded impulses is dependent on time interval during which the gate is open. This statent is clearly understood when comparing the amplitude of records made with 10 and 20 μs references respectively. e rather constant amplitudes of the other records (20 to μs references) are due to the fact that the gate is opened the duration of the whole signal impulse by a single erence at a time, since the length of the reference exceeds t of the signal. A further lengthening of the reference cannot appreciably increase the amplitude recorded. When the reference is approximately equal to, or longer than, the length of the whole double-impulse, the record represents a superposition of the two impulses (see the last record in Fig. 5).

In order to obtain a signal record of high fidelity, a short reference impulse should thus be used. The length of the reference should be well below that of the signal detail to be recorded. As the recorded amplitude decreases with the shortening of the references, the actual length to be used depends to a certain extent on the amplification of the signal before being applied to the detector. The most important limiting factors are definitely the ultimate possibility of producing very short impulses and the design of suitable gating circuits.

ACKNOWLEDGEMENT

The author is indebted to Wilhelm och Martina Lundgrens Vetenskapsfond for financial support.

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Measurement of equivalent noise resistance of a noise thermometer amplifier

By H. Pursey and E. C. Pyatt, Basic Physics Division, National Physical Laboratory, Teddington, Middlesex

[*Paper first received* 1 *December*, 1958, *and in final form* 4 *March*, 1959]

A method is described for the measurement of amplifier noise to an accuracy of better than 1 %. The method involves the determination of the ratio of noise due to the amplifier alone, and the noise due to the amplifier and a wire-wound resistance at a standard temperature. Random errors are analysed, and the effects of systematic errors are discussed.

The work described in this paper forms the first stage in the development of a "Noise Thermometer" for absolute measurement of temperature.

This paper is an account of a method of determining the noise generated by an amplifier. The method has been evolved during the development of a "Noise Thermometer," the purpose of which is to measure absolute temperatures by means of the Johnson noise generated in a resistance element.

Our apparatus is based on a design described by Garrison and Lawson.(1) Their method consisted in balancing the noise from a resistance at the unknown temperature against that from another resistance at a known temperature (e.g. the triple-point of water), the ratio of the two resistances being adjusted until their noise outputs were equal. Then, provided the frequency responses of the two channels were identical, the unknown temperature could be determined simply from the relation:

$$R_1T_1 = R_2T_2$$

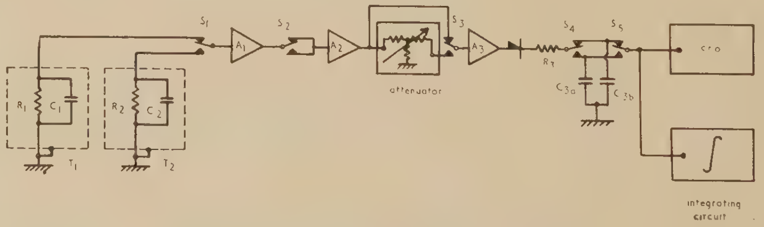
Methods of equalizing the frequency responses, and of obtaining an accurate noise balance, are described in detail by Garrison and Lawson, and also in a report on the equipment by Hogue,(2) of the National Bureau of Standards. Briefly, a vibrating switch is used to feed the outputs from the two sources alternately into a single channel, and a further synchronous switch at the end of the channel separates the signals after rectification and feeds them to independent storage circuits. The signals are then fed to an integrating device which determines the mean difference between the signals over a period of several minutes. The accuracy of the measurement is limited fundamentally by the duration of the integrating process, and it may be shown that the proportional "standard error" of a random signal in a system of bandwidth Δf, averaged over time τ, is equal to $(2\tau\Delta f)^{-1/2}$ (see Van der Ziel(3)).

In such a system, equalization of the frequency responses of the two sources is simply a matter of equalizing the products R_1C_1 and R_2C_2, where C_1 and C_2 are the shunt capacitances across the source resistors R_1 and R_2 respectively. The accuracy to which this "capacitance balance" can be made, together with limitations on the minimum values of resistance needed to obtain a signal appreciably larger than the amplifier noise, sets an upper limit to the frequency of the measuring amplifier. The lower limit is set by the need to obtain good screening and freedom from interference du to the power supplies to the equipment. The range adopte by Garrison and Lawson was from 10 kc/s to 50 kc/s, th limits being determined by resistance-capacitance filters wit fairly gradual cut-off characteristics.

Accurate "capacitance balance" was achieved by means o a second channel a few kilocycles wide, centred on 465 kc/ the output of which was highly sensitive to capacitanc changes. Final balance was realized when the outputs fro both high- and low-frequency channels were zero, th adjustments being slightly interdependent, but with rapi convergence.

LIMITATIONS OF THE APPARATUS OF GARRISON AND LAWSON

The sources of error in the apparatus of Garrison an Lawson are discussed in detail by Hogue,(2) who showed tha the results obtained with the equipment were subject t errors of up to ±0·5%, as against the figure of ±0·1% claimed by Garrison and Lawson. The source of error whic chiefly concerns us in this study is the possible effect of th input impedance on amplifier gain and noise level. Clearly any change in these parameters on switching from one sourc to the other will lead to an erroneous answer. In order t eliminate this possibility, we have developed a system i which the two sources have equal impedance, the differen noise signals being equalized at a later stage by means of a attenuator and a further synchronous switch, which by passes the attenuator when the low-temperature source i connected to the input. We hope in this way, and by mean of other modifications which will be described in a late paper, to obtain a significant improvement on the result reported by Hogue. A block diagram of the equipment i shown in the figure.



Block diagram of noise thermometers

S_2 is a break-before-make synchronous switch, the purpos of which is to disconnect A_2 from A_1 while S_1 is changin over, thereby removing switching transients caused by S from the later parts of the apparatus, where they may other wise cause overloading of the amplifying stages. The cathode ray oscilloscope display enables a rough balance to b ained. The precise balance-point is determined from dings of the integrator, which consists of a further chronous switch, operating as a phase-sensitive detector the output of S_5, and providing a fluctuating d.c. signal ch drives a low-inertia counter unit, type 913 (by Electro-thods Ltd.).

his arrangement suffers from one fundamental dis-antage compared with the system of Garrison and vson. Whereas, in the earlier system, the noise from the plifier was added to two equal noise signals, and hence not affect the balance point, in the present system, the plifier noise is added to two unequal signals, and therefore magnitude must be known before the ratio of the signals be determined. Fortunately, it is possible to make the plifier noise power equal to about a tenth of that generated the low-temperature source, so that the magnitude of the plifier noise need only be known to about one-tenth of accuracy required in the final measurement. Thus, for a % precision in temperature measurement, the equivalent se resistance of the amplifier must be determined to an uracy better than 1%.

METHODS OF MEASURING AMPLIFIER NOISE

he customary method of measuring the equivalent noise istance of an amplifier consists of measuring the power put of the amplifier with several different input resistances, l hence graphically or otherwise determining the residual se attributable to the amplifier alone.

t is, however, difficult to obtain accurate results in this y, the principal sources of error being (*a*) fluctuations in plifier gain, and (*b*) inadequate integration time of ordinary ector circuits. In the noise-balancing apparatus described ove, fluctuations in amplifier gain are averaged by the opping" technique, and the integration can be taken over eriod of several minutes without imposing any exceptional nands on the amplifier gain stability. The detector and egrator circuits are designed so that adequate time of egration can be achieved, and are operated in such a way t the law of the detector is virtually immaterial, since it is d only to compare the levels of two nearly equal signals.

he method consists in connecting a known fixed resistance the ice-point to one input of the apparatus, the other ut being short-circuited. Then, if R_0 is the value of the d resistance and R_{eq} the equivalent amplifier noise istance, the voltage attenuation ratio η required to equalize signals from the two sides is given by:

$$\eta^2 = \frac{R_0 + R_{eq}}{R_{eq}}$$

ence

$$R_{eq} = \frac{R_0}{\eta^2 - 1}.$$

he choice of R_0 is governed by the following considera-ns: On the one hand, it should not be too low, or η^2 will near unity and the value of $(\eta^2 - 1)$ will not be accurately erminable. On the other hand, if R_0 is too large, its noise put will be reduced by shunt capacitance, and this cannot balanced by a capacitor on the other input because this in fact, short-circuited. Also, the effects of feedback eady mentioned will become more noticeable as the value R_0 is increased. In practice, a value between 250 and 0 Ω should be suitable, and we have used two resistors, near 300 Ω and the other near 600 Ω, in order to give independent values of R_{eq}.

he readings are taken in the following way: The two standard resistors are enclosed in copper containers which are immersed in melting ice. One resistor is connected to one input of the noise-balancing equipment, the other input being short circuited. A twisted pair of anti-microphonic concentric cables is used for connexion, one carrying the live lead and the other the earth return. The braiding is used only to earth the copper screens, and is not connected to the standard resistor other than via the amplifier chassis and the earth return lead.

If a suitable attenuator *T*-pad is used, two studs (say *A* and *B*) are found on either side of the balance point, as observed on the screen of the cathode-ray tube. Then, with a process timer set to operate the integrator for five-minute periods, an integrator reading is taken with the attenuator on stud *A*. The phase of S_1 is reversed, and a further reading taken. Two more readings are taken with the attenuator set to stud *B*. The mean of each pair (after allowing for the fact that reversing the phase of S_1 also reverses the direction of the integrator) gives the true integrated magnitude of the difference between the signals from the two channels, and corrects for "zero error" in the integrator (that is, no-signal drift because of slight errors in biasing of the d.c. amplifier), as well as for errors arising from interference from the synchronous switch-drive system, which may leak into the amplifiers and cause a further drift of the integrator. The attenuations of the pad and termination on studs *A* and *B* are then measured by means of a vernier potentiometer, and the attenuation corresponding to equal signals from the two channels is found by linear interpolation.

Thus, if on stud *A* the attenuation is η_A, and the mean of the integrator readings is α, while on stud *B* the attenuation is η_B and the mean of the integrator readings is β, then η, the attenuation required to balance the two signals, is given by:

$$\eta = \frac{\alpha\eta_B + \beta\eta_A}{\alpha + \beta}.$$

Hence, R_{eq} may be calculated.

ACCURACY OF RESULTS

Apart from systematic errors, the accuracy of the measurement is limited by the random nature of the noise, as already mentioned, which gives a standard error on a measurement of a single quantity over a time τ of $(2\tau\Delta f)^{-1/2}$, where Δf is the bandwidth of the system (125 kc/s in this case). Now the capacitors C_{3a} and C_{3b} are each connected to the noise source for about a third of the total integration period, so that the fluctuation of the integrated voltage on either capacitor will be equivalent to a standard error of $(2 \times 100 \times 1{\cdot}25 \times 10^5)^{-1/2}$, or one part in five thousand. The error in the difference between the voltages on the two capacitors, which is also the error in η, will be $\sqrt{2}$ times as great, or approximately one part in 3500, corresponding to an error of one part in 1750 in η^2. The probable fluctuation at 5% significance level of a normally distributed quantity is roughly plus or minus twice the standard error, so the probable fluctuation in the measured value of η^2 will be about ±1 in 900. The precision of the measured value of R_{eq} will be further reduced by subtracting one from η^2, the final error in R_{eq} being about ±1 in 500.

SUMMARY OF RESULTS

The results given in Table 1 were obtained over a period of four days, using two halves of a double triode, type E88CC (by Mullard Ltd.), in parallel for the first stage, and leaving

Table 1. *Experimental values of R_{eq} (in ohms)*

Approx. value of R_0 (Ω)	Time of measurement Tuesday p.m.	Wednesday a.m.	Wednesday p.m.		Thursday a.m.	Thursday p.m.	Friday a.m.		Friday p.m.	
315	186·4	189·6	189·5	189·6	188·2	187·8	186·7	187·0	187·6	187·6
633	185·3	190·2	189·4	190·4	186·7	187·2	185·8	185·8	186·2	186·3

the amplifier power supplies on throughout the period. The pass-band of the amplifier, limited by Zobel-type filter units, was from 15 to 140 kc/s.

Because each measurement is subject to a probable random error of about ±1 in 500, or ±0·4 Ω, it is evident from inspection of Table 1 that there are significant differences between methods, and also between results obtained by the same method at different times. We may analyse the variance of the results by the method of Fisher,$^{(4, 5)}$ and we obtain the values of *F*, the ratio of estimates of variance, given in Table 2.

Table 2. *Ratio of estimates of variance*

Source of variation	*Degrees of freedom*	*Sum of squares*	*Mean square*	*F*
Method of measurement	1	2·24	2·24	6·45*
Time of measurement	9	43·40	4·82	13·9**
Error	9	3·12	0·347	
Total	19	48·76		

The analysis therefore supports the conclusions drawn from inspection of the results, and shows that the variation with time is of greater significance than the difference between the methods of measurement. It is interesting to note that the estimate of error (that is, the residual variation after subtracting "time" and "method" variations from the total) is significantly greater than the theoretical estimate, which may be deduced from the fact that the estimated standard error of each result is 0·1%, or 0·2 units, giving a theoretical variance of 0·04. The corresponding value of *F*, with 9 degrees of freedom for the larger and infinite degrees of freedom for the smaller estimate, is 8·7, while the 1% point for the corresponding numbers of degrees of freedom is 2·4.$^{(6)}$ This discrepancy between theoretical and estimated values may be another aspect of the variation with time, because there is inevitably a delay of half an hour or so between two measurements in one column, so that the variation with time is not entirely eliminated by subtracting the sums of squares of column mean fluctuations.

The four pairs of results obtained on the last day appear to be more consistent than the remainder, and we have therefore thought it worth while to give an independent analysis of them. The result is as follows:

Table 3. *Ratio of estimates of variation for results of last day*

Source of variation	*Degree of freedom*	*Sum of squares*	*Mean square*	*F*
Method of measurement	1	2·880	2·880	10·8*
Time of measurement	3	0·745	0·248	125**
Error	3	0·070	0·023	
Total	7	3·695		

The fluctuation with time is therefore still highly significant, and the fluctuation with method still significant, but the estimate of error is now much closer to the theoretical valu their ratio being no longer significant.

SYSTEMATIC ERRORS

In addition to the random errors mentioned above, t measurements are also subject to certain systematic erro We consider here the following effects:

(1) Shunt capacity across R_0;
(2) Miller effect in the first stage of amplification;
(3) feedback over the whole amplifier;
(4) unbalance caused by extraneous signals entering pri to S_1;
(5) errors in measurement of attenuation;
(6) non-linearity of amplification prior to the attenuat unit;
(7) grid-current noise.

1. The noise output from a resistance *R* shunted by capacitor *C* is given by:

$$\bar{V}^2 = 4kTR\Delta f[1 - \tfrac{1}{3}C^2R^2(\omega_1^2 + \omega_1\omega_2 + \omega_2^2) + \\ + \textit{terms in higher powers of } CR$$

where ω_1 and ω_2 are the cut-off pulsatances of the amplifie Thus, the effective resistance R_{eff} is given approximately by

$$R_{eff} = R[1 - \tfrac{1}{3}C^2R^2(\omega_1^2 + \omega_1\omega_2 + \omega_2^2)].$$

For $R = 633\ \Omega$, $C = 100$ pF, $\omega_1 = 3\pi \,.\, 10^4$ rad/s, $\omega_2 =$ $2{\cdot}8\pi \,.\, 10^5$ rad/s,

$$\frac{R_{eff}}{R} = 1\text{–}0{\cdot}0012$$

while, with $R = 315\ \Omega$ and the other parameters unchange

$$\frac{R_{eff}}{R} = 1\text{–}0{\cdot}0003.$$

The value of R_{eq} obtained from measurements wit $R_0 = 633\ \Omega$ will therefore be 0·09% higher than tho obtained with $R_0 = 314\ \Omega$. This amounts to only 0·15 difference between the two measurements, and is in th opposite sense from the observed error.

2. The ratio of the actual gain γ to the gain γ_0 at lo frequencies, of the first stage of amplification is given by:

$$\frac{\gamma}{\gamma_0} = \frac{1}{\left(1 - \dfrac{\omega^2 C_a C_M R_a R_p R_0}{R_a + R_p}\right) + j\omega\left(C_M R_0 + \dfrac{\mu C_M R_a R_0 + C_a R_a R_p}{R_a + R_p}\right)},$$

where: C_a is stray capacitance between the anode of the fi stage and earth,
C_M is the grid-to-anode capacitance of the valve,
R_a is the anode load resistance,
R_p is the anode impedance of the valve,
R_0 is the resistance connected between grid and earth
μ is the amplification factor of the valve.

For $R_a/(R_a + R_p) = \tfrac{1}{4}$, $R_p = 1500\ \Omega$, $C_a = 100$ pF, $C_M =$ 5 pF, $\mu = 30$, $\omega = 10^6$ rad/s, we find the change in gai on changing R_0 from 300 to 600 Ω is just under 0·07%, th gain being higher when R_0 is equal to 300 Ω. The calculatio ased on a value of ω equal to 10^6 rad/s, which relates ıe upper end of the response of the apparatus. The mean ıge in gain over the band will be about a third of the ve figure, that is, 0·02%, and the corresponding error in will be about 0·04%, or 0·07 Ω. It will again be in the osite sense from the observed error.

his effect is almost negligible in the present experiment, could be significant in a measurement of temperature by method of Garrison and Lawson, particularly as their thermometer resistance was considerably higher than Ω. The calculation gives us a further reason for using mometers of equal resistance.

The degree of feedback over the amplifier (other than described in Section 2 above) cannot be accurately ssed. It is clear, however, that some feedback must ır, because the depth of penetration of an electro- netic wave through a copper plate is of the order of m at 25 kc/s, so that a very thick screen would be needed ive effective shielding. The effect of positive feedback ıld be to increase the value of R_{eq} obtained from a low relative to that obtained using a larger resistance, and therefore account for some or all of the observed repancy. It is important to note that the error in a perature measurement from this cause will not necessarily eliminated by using thermometers of equal resistance, e their differing physical configurations may still lead to erent amounts of feedback in the two channels.

. The effect of extraneous signals entering the system ır to S_1 will be to cause an unbalance which is not ıinated by the phase reversal of S_1 and S_3 described above. wever, its extent is easily estimated by disconnecting the nuator and connecting identical resistances to the two uts. The average integrator reading obtained by phase ersal of S_1 will then be proportional to the difference in extraneous signals at the two inputs. An experiment of kind showed that an unbalance corresponding to about of the amplifier noise power existed, and this could ount for some of the discrepancy between the two methods measurement described above.

o check this point, a set of measurements was taken in ch the input phase was reversed by changing over the ds to R_0 and the short-circuit, instead of by reversing the ve connexions to S_1. For comparison, measurements e also taken by the customary method, and the results set out in Table 4.

Table 4. *Comparison of phase reversal*

R_0 (Ω)	R_{eq} (Ω)	
	drive-reversal	*lead-changing*
315	193·2	192·1
633	191·6	190·1

t appears from these figures that the discrepancy is not ninated by the alternative method of phase reversal. The ct of feedback described in the previous section may ount for the difference between the means of the two umns in Table 4.

. Errors in measurement of d.c. attenuation should be ligibly small, because the measurements are made by ans of a precision potentiometer capable of considerably re accuracy than is required for this purpose. A more blematical question is whether or not the figures obtained h a direct current are valid over the frequency range of noise amplifiers. However, a.c. bridge measurements at c/s and 100 kc/s showed that the difference between the attenuations at these frequencies on any stud setting was never greater than 0·004 dB, or 0·1% power-ratio change. Furthermore, the attenuation at 1 kc/s was in close agreement with a corresponding d.c. measurement. Thus, because the error is proportional to f^2, the integrated error in attenuation over the frequency band is not likely to be more than 0·05%, which would not contribute significantly to the observed discrepancies in R_{eq}.

6. To check the effect of non-linearity of the amplification prior to the attenuator panel, a measurement was made with a 10 dB attenuator pad inserted between the output of the first amplifier and the input of the first filter and amplifier panels, so that the stages immediately prior to the attenuator unit were working at a lower level than usual. The discrepancy in R_{eq} still persisted, showing that the effect of non-linearity was not important, and also that, if the discrepancy was caused by feedback, then this must be occurring before the additional attenuator pad, that is, in the first amplifier panels.

7. The effect of grid current on the noise signal is discussed by Garrison and Lawson,(1) who conclude that, if the input resistance on the grid of the first amplifier is 6 kΩ, the error introduced is less than 0·03% provided the grid current is less than 10^{-9} A. For the low input resistances used in the present experiments the error will be proportionally smaller, and may be neglected as long as the grid current is not greatly in excess of the above figure. A recent discussion of grid current in electron tubes by Fairstein(7) gives the following empirical formula for the grid current in a receiving triode in terms of E_{g-a}, the grid-to-anode potential, and I_k, the cathode current:

$$I_g = E_{g-a}^{3/2} I_k \times 10^{-10} \text{ A}.$$

Thus, for

$$I_k = 15 \text{ mA},\ E_{g-a} = 100 \text{ V, we find } I_g = 1\cdot5 \times 10^{-9},$$

so that errors from this source should be negligible.

CONCLUSIONS

The results indicate that the noise thermometer electronic equipment is capable of measuring its own amplifier noise to an accuracy of better than 1%, which includes errors arising from instability over a period of a few hours in the quantity being measured. This would be quite adequate for a temperature determination by the method described, using thermometer elements of equal resistance, to an accuracy of 0·1%, but would need to be improved before the ultimate accuracy of 0·01% could be achieved.

It follows from the results of the statistical analysis that we are not concerned solely with errors due to inadequate measuring technique, but that R_{eq} does in fact vary significantly over a period of a few days. There are several possible causes of such variations, including changes in the position of the electrodes of the first valve, particularly such changes as will alter the spacing between grid and cathode. This would alter the value of the mutual conductance of the valve, which is inversely proportional to its equivalent noise resistance. It is also likely that spontaneous changes in cathode emissivity will occur, and this too would change the value of R_{eq}, which depends in a complex way on the quality of the cathode of the valve.

There is evidently a need for further research to investigate fully the causes of these and other effects which may contribute to the instability of R_{eq}.

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Double-beam infra-red grating spectrometer

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An infra-red foreprism-grating spectrometer of compact design is described. Non-precision components are used in the instrument which nevertheless has a high performance. Two 2400 lines/in. gratings are used in the first order to cover the wavelength range 2 to 17 μ. A ratio-recording double-beam system is employed.

INTRODUCTION

The production of replica echelette gratings of high quality and low cost(1–2) is resulting in increased usage of such gratings for routine spectroscopic measurements. Wide-range grating spectrometers are now available commercially, usually as modified versions of prism spectrometers.

It is often stated that the performance of a rocksalt prism spectrometer is adequate to resolve the comparatively broad bands of organic solids and liquids. This statement is not completely true in view of the poor resolution of such equipment below wavelengths of about 7 μ. The main advantages of a grating spectrometer compared with a prism spectrometer may be summarized as follows.

The high dispersion of a grating throughout its wavelength range results in a consistently high resolution. The resultant spectral bandwidth is generally a good deal less than the width of absorption bands in solid and liquid materials. Optical density data for these bands will therefore be relatively unaffected by moderate changes in slit width. Such data can thus be transferred reliably from one grating spectrometer to another, a condition that rarely applies to prism spectrometers.

Due to the high dispersion of the grating, spectrometer slit widths are considerably larger at short wavelengths by comparison with a rocksalt prism spectrometer using a similar radiation detector. This makes the slit design less critical with regard to quality and alinement of the slit jaws. Moreover the effect of small amounts of optical aberration in the grating collimating system is small with these wide slits, so that high-aperture spherical mirrors can be used, even with gratings of large area.(3)

The wavelength scale associated with a prism spectrometer is dependent on refractive index of the prism material and hence the calibration is dependent on temperature, but this is not the case with a grating spectrometer. Moreover the angular rotation of the grating to cover a given wavelength range is considerably higher than that of a prism, so that the wavelength measurements on a grating spectrometer can be made with consistently high precision.

A preliminary stage of dispersion is desirable in a wide-range grating spectrometer and this results in a very low level of spurious radiation of wavelengths other than that be measured by the radiation detector.

These advantages over a prism instrument justify the co struction of a grating instrument even although a dou monochromator must be used. The equipment descri below, which employs two gratings in the first order, intended for routine use where compactness in design is primary consideration.

DESCRIPTION

General layout. The optical components of the spect meter are mounted on a base of $\frac{1}{2}$ in. Duralumin s 30 × 27 in., and are enclosed in an airtight case with $\frac{3}{8}$ Duralumin walls and a $\frac{3}{8}$ in. Perspex lid 7 in. above the ba Radiation from the 2 mm diameter Nernst source *N* [Fig. 1(enters the spectrometer case *via* a 1 × 1$\frac{1}{2}$ in. potassiu bromide window *W* and sample cells are placed at foci the source in wells with potassium bromide windows Introduction or removal of samples does not therefo disturb the dry atmosphere of the spectrometer. The ca is heated to about 5° C above room temperature by a 60 non-thermostatted heater mat, to prevent attack atmospheric water on the outside of the salt windows.

Two removable trays of phosphorus pentoxide within t case keep the moisture level down to about r.h. 3%. stream of dry carbon dioxide-free air is passed into t spectrometer at about 30 ml./min to reduce the effect fluctuations in atmospheric pressure and temperature on t volume of dry air in the spectrometer case. The excess a escapes through slight leaks along the shafts of the slit drive

The mechanical drives associated with the slits and th wavelength cams are mounted below the spectrometer ba The 7$\frac{1}{2}$ in. diameter sector disk *SE* [Fig. 1(*a*)] protrud through a slot in the spectrometer base and is enclosed by box extension. A type F.P. 10 induction motor (by Birmin ham Sound Reproducers) supplies a nylon belt drive to th sector rim,(4) and is mounted within the wall of the spectr meter case. A small fan wheel on the motor shaft keeps th spectrometer atmosphere well mixed.

Optical components. The optical layout of the spectr meter is shown in Fig. 1.

The alternate-path section shown in Fig. 1(*a*) has an erture of $f/3{\cdot}5$. This large aperture necessitates taking the beams of radiation from the same area of the radiation irce N and the arrangement shown achieves this by the of a single rotating sector SE. The variation in time of radiation falling on the thermopile is not far removed m a square waveform, being determined by the vertical erruption of the source focus N' following M_2 [see side w of SE in Fig. 1(*a*)]. The sector switch RS and the rim ve have been described previously[4,5] and the new sector sign is shown in Fig. 1(*a*).

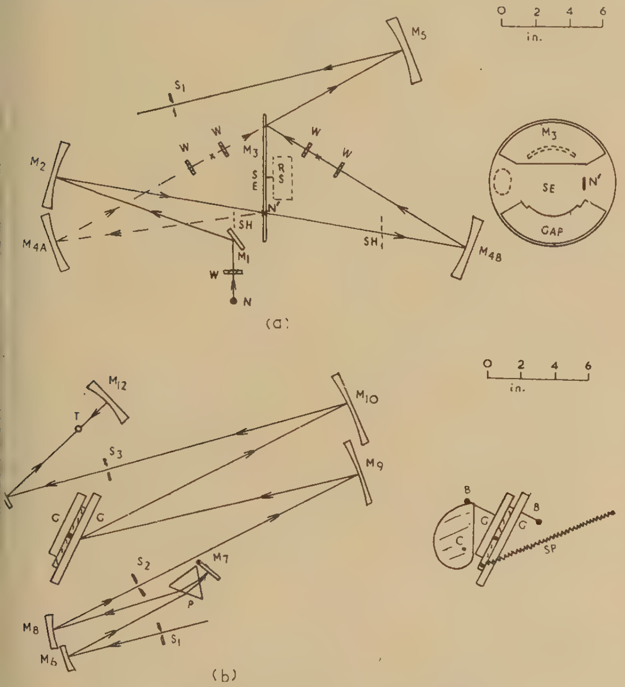

Fig. 1. Optical system of spectrometer
(*a*), alternate-path system; (*b*), prism and grating monochromators

$M_{1,3,7,11}$, plane mirrors (M_3 is aluminized on both sides); $M_{2,5}$, 4 in. diam., 7 in. f.l.; $M_{4A,B}$, 3½ in. diam., 6 in. f.l.; $M_{6,8}$, 2 in. diam., 6 in. f.l.; $M_{9,10}$, 4½ in. diam., 15 in. f.l.; M_{12}, 3 in. diam., 2 in. f.l. (foci at 2¼ in. and 14 in.); N, Nernst filament radiation source; N', image of source at SE; SE, sector disk, of which the side view is shown separately; RS, rotary switch on sector shaft; SH, shutters; W, potassium bromide windows; S_{1-3}, slits; P, potassium bromide foreprism; G, gratings; B, ball race, bearing against C; C, grating wavelength cam, under tension from SP; SP, over-centre spring; T, thermopile detector.

The foreprism section shown in Fig. 1(*b*) consists of a odified Ebert system,[3] focal length 6 in., aperture $f/4$. The tical definition of this section does not need to be high, ice the width of the entrance slit S_1 is set manually at 1 and mm for the wavelength ranges 2 to 5 and 5 to 17 μ respec- ely, in normal first-order grating operation. Under these nditions the foreprism Littrow mirror M_7 is rotated by a m, on the shaft which drives the grating (see below). The mensions of this cam are not particularly critical and the ntour was found experimentally using a scriber in place the ball-race which normally bears against the cam. The ttrow mirror was set manually with a worm gear drive to e peak energy output at first order grating wavelength ervals of about $0{\cdot}25\ \mu$. The cam blank was scribed at ch interval and the cam contour constructed from the sultant scribed outline.

If it is necessary to isolate a higher grating order a somewhat smaller entrance slit width must be used, and the foreprism Littrow mirror is rotated manually to give the required setting. A 60° potassium bromide foreprism P, size of face 2¼ × 1½ in. high, has adequate resolution to isolate grating orders effectively up to the fourth order.

The grating section also consists of a modified Ebert system, focal length 15 in., aperture $f/4{\cdot}5$. Two 2400 lines/in. gratings G are used, one of size 4 × 3 in. with maximum blaze at 3 μ (N.P.L. cylinder no. 274F), the other of size 6 × 3½ in. with maximum blaze at 10 μ (N.P.L. cylinder no. 314A). They are mounted back to back on a brass plate which is pivoted between two ball-bearings. Two precision ball-races B are mounted on arms attached to this plate, which is rotated when the wavelength is scanned by a precision spiral cam C bearing against one of the ball-races. This cam and the foreprism wavelength cam are mounted on the same shaft. The gratings are interchanged by rotating the mount manually until one of the ball-races engages the cam on the opposite side from the other ball-race. A milled knob external to the case is used to effect this interchange and to supply loading between the ball-race and the cam by means of the over-centre spring SP.

A Hilger–Schwarz thermopile no. FT 20 is used for the detection of radiation. A spherical condensing mirror M_{12} is situated on axis, giving a 6 : 1 reduction in the image of slit S_3 at the detector T. The effective length of the slit is about 20 mm and since this model of the thermopile possesses an element of size 4 × 0·2 mm the reduced image can be accommodated for slit widths up to about 1 mm. The optical aberrations attendant on the use of a spherical mirror instead of an ellipsoidal mirror undoubtedly cause some loss of signal at the thermopile, but this loss is not serious and does not justify the use of an aspherical mirror. The mount for the thermopile mirror M_{12} has screw settings which greatly simplify the adjustment of focus to give optimum signal.

The experience gained during construction of the spectrometer has suggested a more compact optical layout. If the alternate-path section were scaled down to three-quarters of its present size, and if S_1 and M_6 were moved 2 in. to the left in Fig. 1(*b*), the layout could be accommodated in a case 24 × 24 × 6 in. This would result in a considerable reduction in the volume of air to be kept dry.

Mechanical components All slit mechanisms are of the Sears type, involving two arms pivoted on steel strip hinges. The foreprism entrance slit S_1 (Fig. 1) has curved jaws of radius 62 mm masked to 20 mm length, while the slits in the grating section have straight jaws. The slit mechanism of S_1 has its strip hinges inclined at about 45° when the slit is closed, so that there is only a small amount of vertical movement as the slit opens and the optical quality of the foreprism section is relatively unaffected by the small change in height of the slit centre. As has been mentioned earlier the slit S_1 is set manually, but the other slits S_2 and S_3 are linked to a servo-motor by a 95 : 1 worm gear drive and are monitored automatically to give a constant reference energy output.[4]

The grating drive is taken from another type F.P.10 induction motor *via* a clutch and three-speed gearbox (3 : 1 ratios). The final step in the drive consists of a 150-tooth precision gear wheel on the grating cam shaft, which is engaged by a precision worm gear. A cam on the worm gear shaft is arranged to trigger a microswitch once every revolution. Contact pulses[5] from this microswitch supply the wavelength calibration marks on the chart record. Another microswitch with a gear is so arranged that every fifth pulse from the first microswitch is recorded. An alternative scheme, in which four pulses are recorded and the fifth omitted, is used where a finer wavelength scale is required. A Veeder counter is set up to give a direct indication of the reference number of any one wavelength calibration mark.

All rotatable shafts passing into the spectrometer case are rendered air-tight, usually by spring-loaded washers bearing against rubber O-rings.

Electronic amplifier. The ratio-recording system is preferred to the more commonly-used "energy limitation" arrangement. Advantages include avoidance of a precisely-constructed optical attenuator, uniform recorder response over the whole transmission range, automatic universal slit width control, and simple electronic conversion to single-beam or expanded scale operation.

The amplifying and recording equipment has been described previously.[(4,5)] The only further change is in the pre-amplifier, where the feedback chain between the anodes of the two valves has been removed, and a parallel feedback loop has been taken from the anode of the second valve *via* a $2 \cdot 5$ MΩ resistor and 2 μF capacitor to the correct side of the input transformer primary winding. This arrangement results in a threefold reduction in gain with our input transformer. The low-frequency response of the transformer is thereby improved considerably, resulting in more efficient rectification.

A feature of the present instrument is that up to five-fold scale expansion can be achieved at any part of the transmission scale. The recording potentiometer slide-wire is made part of a resistance chain and its position in the chain (and hence its mean potential) can be varied by a 2 pole-6-way switch. This adjustment is made in conjunction with the existing output ratio control which determines the amount of scale expansion achieved.

PERFORMANCE

When the humidity of the spectrometer atmosphere is reduced to about r.h. 3%, the intensity of the strongest water vapour absorption bands is reduced to about 25% absorption. This includes a 5 cm path at atmospheric humidity in the cell well, and a somewhat shorter path at the radiation source. On traversing these absorption bands at the fastest scanning speed of $0 \cdot 75$ μ/min a small amount of disturbance occurs, about ± 1% transmission in magnitude. This is associated with the low alternating speed of the sample and reference radiation beams, which is comparable with the comparatively rapid rate of change of signal under these operating conditions. At slower scanning speeds the amount of disturbance is reduced.

The 100% transmission baseline is flat to within ±1% transmission throughout the wavelength range apart from a shallow band near $9 \cdot 8$ μ which may arise from one of the potassium bromide windows.

When a grating cam in the form of a simple spiral is used the wavelength scale is virtually linear for the short wavelength grating. For the long wavelength grating which rotates through a much larger angle the scale becomes appreciably non-linear beyond about 12 μ. This lack of linearity is accepted since the scale is calibrated empirically, using emission bands from a mercury lamp and absorption bands of water (and of ammonia if desired) in the first, second and third orders with existing wavelength data.[(6,7)]

The spectral bandwidth of the spectrometer is about 5 cm^{-1} at 3000 cm^{-1}, $1 \cdot 5$ cm^{-1} at 1500 cm^{-1} and better than 1 cm^{-1} at 700 cm^{-1}. The degree of resolution of water vapour and carbon dioxide bands is equivalent to that associated with precision equipment[(8)] so it appears that very little loss in performance has resulted from the use of spherical optics, straight slits and the Ebert mounting.

The scanning motion is normally shut off automatically at 5 and 17 μ, but the wavelength limit can be extended to about 19 μ on increasing amplifier gain and response time and reducing the speed of wavelength scan.

DISCUSSION

The compact, simplified design adopted for the present equipment results in a resolving power which is superior to that attainable in a prism spectrometer. To obtain yet higher resolution it would be necessary to alter several features. Increase in focal length of the collimator and in grating area would result in improved resolution but would increase the size of the spectrometer considerably.[(3)] To obtain increased dispersion at short wavelengths a 7500 lines/in. grating could be used in place of the present 2400 lines/in. grating, a step which would necessitate certain design modifications, described below.

The use of a 7500 lines/in. grating at short wavelengths in the first order gives a wider effective blaze and generally better resolution than a 2500 lines/in. long wavelength grating in the third order, with the result that the range 2 to 5 μ can be covered in one step.

However, at high angles of grating incidence in an Ebert system the disposition of the grating should be such that the diffracted beam of radiation is narrower than the incident beam, as seen in Fig. 1(*b*). This condition should be fulfilled for a 7500 lines/in. grating used at short wavelengths in the present arrangement, so that it would be more satisfactory in this case to use separate wavelength cams for the two gratings. The cams would be mounted one above the other and one would have to increase in radius during the wavelength scan while the other would have to decrease in radius. If each cam covered its respective wavelength range in half a revolution it would still be possible to use one foreprism cam.

It is considered that the present arrangement for covering a wide wavelength range using two gratings in the first order has several advantages over the more usual arrangement employing one grating in several orders. Only one foreprism is required in the present arrangement, with only one wavelength cam, whereas the alternative arrangement usually requires two foreprisms and four wavelength cams, to cover the whole wavelength range in four steps instead of two as at present. Interchange of the two gratings in the present approach involves a change in width of the foreprism entrance slit, but no other operations are necessary.

ACKNOWLEDGEMENT

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Improved polythene-shielded net radiometer

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An improved net radiometer using very thin hemispherical polythene windshields is described. Balanced radiant heating of the windshield prevents formation of dew. Two of these instruments, suitably matched, permit direct measurements of radiative flux divergence in the lowest few metres of the atmosphere, with an accuracy of at least 10%. Some preliminary results are given.

asurement of the divergence of radiative flux near the und necessitates the use of small and sensitive net radio-ters, with high short-term stability and low susceptibility wind-speed effects. In addition, the air stratification near instrument should not be disturbed.

t least two un-aspirated instruments using polythene as a dshield have already been constructed, one by Schulze,⁽¹⁾ one by Suomi.⁽²⁾ The former, apart from being too ky for the present purpose, uses rather thick polythene. e latter is not sufficiently accurate. Both are affected by v.

ecause none of the existing instruments seemed to fulfil the above requirements, an improved type of net radio-ter with a very thin hemispherical polythene shield was eloped in the Division of Meteorological Physics. Instru-nts of this kind have been found capable of being matched ficiently well to measure directly extremely small dif-ences in radiative flux, thus permitting the accurate ermination of flux divergence in the lowest few metres. revious determination with an actinometer (Robinson⁽³⁾) s considerably less precise, mainly because of the double-erence technique required.

THE INSTRUMENT

a) *General.*—As can be seen from Fig. 1, the instrument sists essentially of a polythene windshield in the form of two hemispheres surrounding the actual sensitive element. The latter follows standard practice and consists of two rows of thermojunctions, separated by a sheet of plastic material and sandwiched between two aluminium plates, the exterior surfaces of which are spray-painted black with optical matt-black lacquer type MFB (by Thos. Parsons and Sons Ltd.) as recommended by the Radiation Commission of I.A.M. The junctions are all in series, those from the lower row alternating with those from the upper row. Such a thermopile is readily obtained by winding fine constantan wire on a rectangular Perspex former and simultaneously copper-plating half of each turn of the coil thus formed. The detailed construction is similar to that described by Deacon⁽⁴⁾ for soil heat-flux plates. The junctions are electrically insulated from the aluminium plates by 0·0015 in. sheet polythene. A good thermal contact is thus assured.

(*b*) *The windshield.* The use of polythene for the windshield was adopted because it is the only material known that is transparent in the short- and long-wave region. Fig. 2 shows the spectrum of polythene as given by Schulze.⁽⁵⁾ Polythene has absorption bands around $3\cdot5\ \mu$, $5\ \mu$, $7\ \mu$ and $14\ \mu$, but these are narrow and do not influence the accuracy of the measurements very much, as has been shown by Bolle.⁽⁶⁾

Because the instrument had to fulfil the cosine-law, the main difficulty consisted of producing sufficiently thin polythene hemispheres. This was overcome by the vacuum-

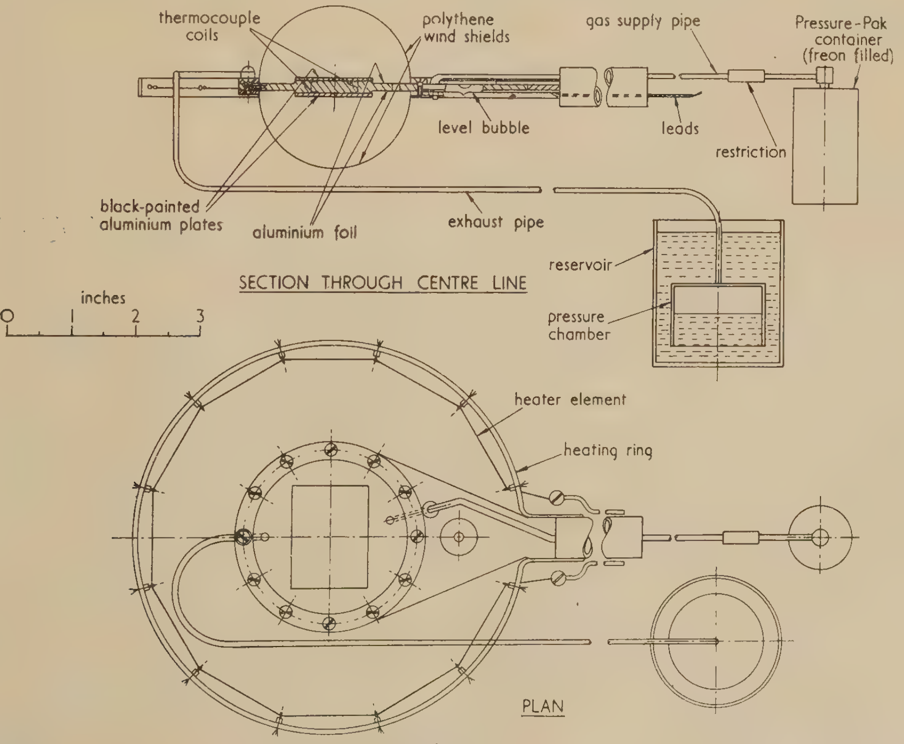

Fig. 1. Schematic arrangement of the radiometer

forming of 0·004 in. polythene sheet, which gave hemispheres about 0·002 in. in average thickness, with a maximum variation from point to point of less than ±0·0004 in.

A polythene sheet was stretched across the top of a mould consisting of a hollow polished-brass hemisphere with flange and clamping ring. The hemisphere was perforated by pin-holes 0·008 in. in diameter about $\frac{3}{16}$ in. apart. The sheet was then brought almost to melting point by radiant heating, and quickly sucked into the mould. Upon completion, the hemispheres are also coated with a thin film of silicone oil to facilitate the run-off of rain water. In service, this film must be renewed periodically.

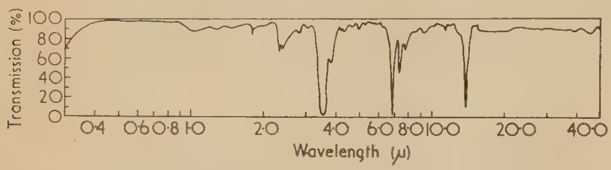

Fig. 2. Transmission of polythene (Lupolen —H) 0·1 mm thick, after Schulze(5)

Polythene slowly deteriorates through the action of ultra-violet sunlight, which causes photo-oxidization. The effects of this are first noticed in the infra-red region where new absorption bands appear at 3 μ, 8·5 μ and 10·65 μ.(7) Later, discoloration and increased turbidity appear. Both the meagre information available from the makers and the experimental results available so far, point to a useful life for a hemisphere of six months in Melbourne. In other localities, this figure will undoubtedly vary according to the total amount of ultra-violet light received during the period, i.e. according to latitude, elevation and cloudiness. This point is under investigation. The hemispheres themselves are easily replaced on removal of two clamping rings secured by twelve screws.

Since polythene hemispheres of this thickness possess little rigidity of their own, they have to be kept inflated. This is being accomplished by charging them up with dry Freon 12 from a "Pressure Pak"* container (see Fig. 1). The constant liquid-head device forming the end of the exhaust tube acts in three ways: as a valve, as a pressure regulator and as a low-pressure gas reservoir.

Because of the comparatively high water-vapour permeability of polythene, the gas inside the hemispheres must be renewed every 48 hours to avoid internal condensation. The future use of a low-flow valve permitting a permanent gas circulation is contemplated. The gas supply contained in a 6 oz "Pressure Pak" is sufficient for almost a year's operation. This system provides more effective protection against condensation than air dried by silica-gel, except when the latter is placed inside the hemispheres which, because of the frequent renewals necessary, is inconvenient.

(*c*) *The heating ring.* On clear nights, the radiant cooling of the hemispheres themselves is not appreciable at first, mainly because of the low emissivity of polythene. Nevertheless, the smallest dew deposit immediately "blackens" the surface for long-wave radiation and, because the hemispheres are thermally insulated, makes them ideal for further dew deposition.

To overcome this, an external heating ring was installed around the instrument in the horizontal plane of symmetry. It consisted of a single 40 s.w.g. nichrome wire carried on insulated supports projecting inwards from a shallow cylindrical reflector (see Fig. 1). The radiant energy from the heater very effectively keeps the temperature of the hemispheres above ambient temperature without influencing the readings of the instrument because the blackened surface cannot "see" the ring, and the amount of scattered energy received from the hemispheres is both small and symmetrical.

Positioning of the ring is not very critical and switching the heater on or off does not show on the recorded trace. The heating power used so far is 15 W and is switched on only during the night by means of a time switch.

CALIBRATION

(*a*) *Long wave.* The procedure was similar to that used by MacDowall.(8) The instrument was placed inside the copper calibrating box shown in Fig. 3 and a cavity black body placed opposite its aperture. The box was insulated with Onazote (by Expanded Rubber Company Ltd.) on the outside and painted black on the inside. The temperature of the box and cavity were determined with thermometers in good contact with the surfaces concerned. It is shown in the appendix that the net long-wave flux R_L received by the element is given by*:

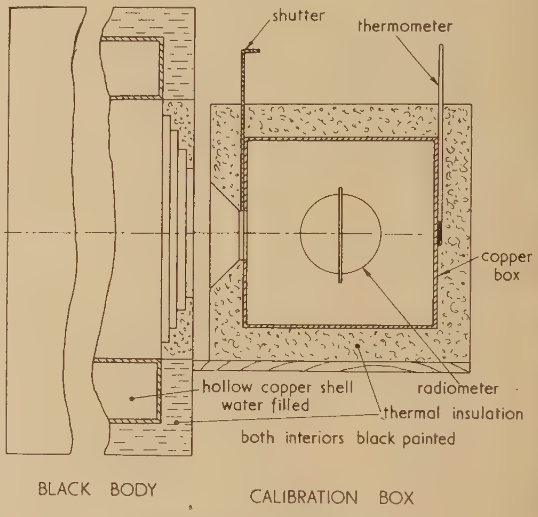

Fig. 3. Long-wave calibration apparatus

$$R_L = \psi\sigma[T_1^4 - \epsilon T_2^4 - (1-\epsilon)T_3^4] \qquad (1)$$

where T_1, T_2 and T_3 are the absolute temperatures of the black body, the calibrating box and the element, ϵ is the effective emissivity of the calibrating box, σ is the Boltzmann constant and ψ is the effective aperture (which is given by $\psi = J/J'$, where J' is the black-body radiation the element would receive from a solid angle of 2π, and J is the radiation actually received through the aperture). ψ is best calculated after Bossy.(9)

If $T_3 = T_2 + \Delta T$ and if ΔT is assumed to be small equation (1) becomes approximately:

$$R_L = \psi\sigma[T_1^4 - T_2^4 - 4\Delta T\, T_2^3(1-\epsilon)] \qquad (2)$$

ΔT will hardly exceed 1° C if the element is kept inside box for any length of time and is only exposed to the k body for short periods. In addition, because ϵ is better ı 0·9, the term containing ΔT becomes negligible if $- T_2$ is greater than 40° C. R_L is then found to be ependent of ϵ and is given by:

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* A commercially available pressurized container (by Parco Chemicals Pty Ltd.), used for spraying insecticides, etc. Freon 12 (Dichlorodifluoromethane), a commonly used vehicle in these applications, is readily available in extremely pure and dry form.

* MacDowall(8) gives an incorrect expression, $R_L = \psi\sigma(T_1^4 - \epsilon T_2^4)$

$$R_L = \psi\sigma(T_1^4 - T_2^4) \qquad (3)$$

) *Short-wave.* The short-wave calibration was carried by pointing the radiometer at the sun by means of a oter temporarily attached. Next, the radiometer was ded from the sun by a little disk fixed at a distance. The erence between the unshaded and shaded readings, being rly equivalent to the direct solar radiation, was then npared with the reading from a Linke–Feussner actinoer, also pointed at the sun. This method, apart from ng quicker, is more accurate than the usual one, especially ow solar elevations.

he instrument was found to be 4% more sensitive in the rt- than in the long-wave region; this is attributed mainly he lower absorption of the blackening in the long-wave ion.

) *Dependence of sensitivity on wind speed and angle of dence.* In wind-tunnel tests, the sensitivity was found to y by less than 1% over a wind-speed range of 0–15 ms^{-1}. On calibrating in the long-wave region with and without nispheres, a difference in sensitivity of 9% was found. e reflexion coefficient C for vertical incidence is given by snel's law as:

$$C = \frac{(1-n)^2}{(1+n)^2} \qquad (4)$$

ere n, the refraction coefficient, is 1·51 for polythene in visible region (Aggarwal(7)) and certainly not less than in the infra-red region (Grimsehl(10)). C therefore omes 4% per reflecting surface or 8% for the front and k surfaces together, leaving only 1% to be accounted for absorption. Because the thickness variation of the hemieres is not more than ±20%, the maximum cosine error oretically possible for long-wave radiation resulting from iation of absorption with angle of incidence would be ·2%. For short-wave radiation, this should be lower l, because polythene has little absorption in that region. mall but systematic deviations from the cosine law could arise from variations with angle of incidence in the orptivity of the blackened surfaces. Chance deviations at ticular angles could arise from contamination of either polythene or the blackened surfaces. However, in ctice, a change of hemispheres, not visibly damaged, has er been found to alter the calibration of the instrument more than ±1%, whether in the long-wave or the shortve region. Moreover, for the range of angle of incidence 0–75°, tests have shown a maximum variation in short-wave sensitivity of ±1·5%.

MEASUREMENT OF FLUX DIVERGENCE

For this purpose, two radiometers are first mounted side by side over the chosen site, thus being subjected to the same net radiative flux R. The two instruments are connected in opposition and the more sensitive one shunted. The shunt is adjusted to give a null reading on the galvanometer, thus equalizing the two sensitivities. The required resistance of the shunt will normally be much larger than that of either radiometer and, hence, need not be known precisely in order to calculate the overall sensitivity of the combination.

Next, one of the radiometers is moved to a different height. The deflexion of the galvanometer is then a measure of the flux difference between the two levels, and the flux divergence *div R* is simply obtained by dividing this difference by the difference in height. Considerably greater accuracy is obtainable in this way than by taking the difference of independent measurements at the two levels.

PERFORMANCE

So far, measurements of *div R* have been carried out at Edithvale on a number of nights, the radiometers being mounted at heights of 0·25 and 1·75 m, but future work will cover heights up to 30 m. Values of *div R* and *R* on two calm nights are given in the table. It should be pointed out that the amount of scatter was surprisingly small and was, on the average, less than 1 part in 10.

Values of radiative flux and flux divergence on a clear night at Edithvale

Date	*Time (p.m.)*	*Air temp. (°C)*	*Water vapour pressure (mb)*	*Radiative flux R at 1·75 m (mW.cm^{-2})*	*Flux divergence R* (μW.cm^{-3})*	*Radiative cooling rate* (°C h^{-1})*	*Remarks*
.9.58	8.45	10	8·1	14·1	0·61	1·7 ± 0·1	Clear sky
	9.30	9·5	8·1	14·1	0·94	2·6 ± 0·1	
	10.00	9	8·0	14·0	0·96	2·6 ± 0·1	
.9.58	9.00	11	11·8	1·8	0·35	0·9 ± 0·1	Clear before measurements commenced. Increasing middle cloud during measurements
	9.30	11	11·6	1·0	0·36	0·9 ± 0·1	
	10.00	11	11·2	1·0	0·27	0·7 ± 0·1	
	10.30	11	10·0	1·2	0·26	0·7 ± 0·1	

* Average from 0·25 to 1·75 m.

When measuring flux divergence, heating rings cannot be used continuously, because this would severely alter the fine structure of the radiation field. Dew can, therefore, occasionally form on the hemispheres, but these are easily dried by brief periods of heating. Differential heating effects will rapidly decay, so that readings can be resumed within a few minutes.

Apart from the application described above, several of these instruments have been in regular use for some time at various Australian stations recording net radiation.

ACKNOWLEDGEMENTS

The writer is indebted to Mr. W. C. Swinbank and Mr. E. L. Deacon for valuable advice, and to Mr. G. Vanderheiden for the excellent construction of the instruments.

Note added in proof. Further work has shown that Freon is unsatisfactory as a dry gas supply and it has been replaced by dry nitrogen.

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APPENDIX

Net radiative flux received by the element during long-wave calibration. The flux R_1 received on the front surface (facing the black body) assuming the element to have unit emissivity is given by:

$$R_1 = \psi\sigma T_1^4 + \epsilon(1 - \psi)\sigma T_2^4 - \sigma T_3^4 + (1 - \epsilon)(1 - \psi)\sigma T_3^4 \qquad (1a$$

The terms on the right are respectively the fluxes receive from the black body through the entrance aperture and fro the calibrating box, the flux lost from the element into th hemisphere, and the flux from the element reflected bac from the walls of calibrating box. No flux from the elemen is returned from the entrance aperture, since the black bod has unit absorption.

The flux R_2 on the back surface is simply

$$R_2 = \epsilon\sigma T_2^4 - \sigma T_3^4 + (1 - \epsilon)\sigma T_3^4 \qquad (2a$$

where the right-hand terms are analogous to the last thre terms of equation (1*a*).

The net long-wave flux is therefore given by:

$$R_L = R_1 - R_2 = \psi\sigma[T_1^4 - \epsilon T_2^4 - (1 - \epsilon)T_3^4] \qquad (3a$$

as in equation (1), p. 268.

An emissivity of the element ϵ_1 differing from unity woul only mean that the right-hand sides of equations (1*a*), (2 and (3*a*) had to be multiplied by ϵ_1. An allowance for thi is automatically absorbed in the calibration constant.

Instrument for measuring liquid flows of less than a millilitre per hour

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[*Paper received* 4 *December*, 1958]

Flow is channelled through a narrow passage containing thermojunctions placed before and after a heated wire. The differential e.m.f. is proportional to the flow when this is small, up to 150 μV for 5 ml.h^{-1} in the existing instrument. Suitably large collectors buried in porous material can channel seepage into the instrument. Flows of 0·005 ml.cm^{-2}h^{-1} (to 20%) have been measured in this way in a river bed.

The present instrument has been developed to measure the natural rate of water seepage near the surface of the ground. It has been used, for instance, to measure the slow upward seepage of water through the sandy bed of a river. The instrument consists essentially of a narrow passage through which the water is channelled, and this passage is crossed by a heater wire with thermocouple junctions placed before and after it in the line of flow. A sensitive potentiometer and galvanometer are used to measure the e.m.f. of the thermocouple. This e.m.f. depends upon the fluid velocity in the manner of the calibration curves shown in Fig. 2. The present instrument is an adaptation of one used previously by Benseman and Donaldson(1) and the design has been made simple so that large numbers can be constructed easily.

CONSTRUCTION

Two disks of bakelite, diameter 1¾ in. and ¼ in. thick, are bolted together to form the body of the instrument, as in Fig. 1(*a*). The matching faces of the disks are shown in Fig. 1(*b*) and (*c*). Holes *S* and *T*, one in each disk, are ports for the entry and exit of water. They are linked by a narrow channel, ⅛ in. diameter, that follows the rectangular course *SFGT* between the two disks. The heater wire of 36 s.w.g. constantan is threaded in succession through holes *X*, *X* and *Y*, *Y* drilled through the bakelite disks so as to intersect the flow channel. The thermocouple wires lie in fine grooves cut in the faces of the disks at right angles to the flow channel. The junctions, of which there are eight, must be small so as

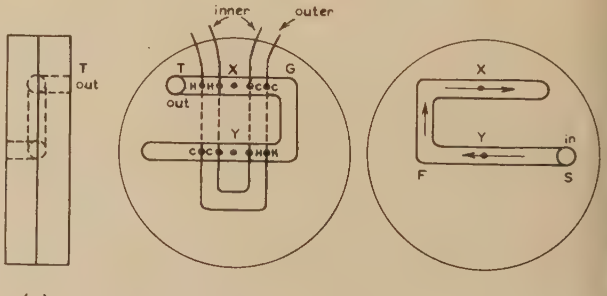

Fig. 1. The hot-wire flowmeter. The instrument is shown assembled at (*a*) and opened at (*b*), (*c*) to show the U-shaped flow channel *SFGT*, the heater wires at *X* and *Y*, and eight thermojunctions marked *H*, *C*, combined in two sets of four

t to obstruct the fluid flow, and they are formed by cutting ips from a metal ribbon 2 cm wide and 0·006 cm thick of ich one half of the width is copper and the other half nstantan* (Huebscher, Schutrum and Parmelee[(2)]). A ip about 0·025 cm wide forms a single junction.

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* Now at the Physics Department, University of Canterbury.

The arrangement of the junctions is shown in Fig. 1(*b*). ur in series are set close to the heater wire, forming a ferential system. The diagram shows the copper wires of rmopiles as full lines and the constantan wires as broken es. It also shows which junctions become hot (*H*) and ich remain cold (*C*) when fluid flows around the rectangular annel past the heater wires. The total e.m.f. is proportional the sum of the temperature differences produced by fluid w in the parallel arms of the channel.

A further set of four junctions is arranged at greater tances from the heater wires, for a purpose explained in next section.

FEATURES OF THE DESIGN

A hot-wire flowmeter is usually sensitive to orientation cause heated fluid tends to rise from the hot wire. In the esent instrument, the channel is arranged to follow a tangular course so that, by placing a heater wire and rmojunctions in parallel arms, the whole system may be ensitive to orientation.

A system having calibration curves like those of Fig. 2 n be ambiguous because an observed e.m.f. may signify her of two rates of flow, one large and one small. The nbiguity can be resolved in the following ways:

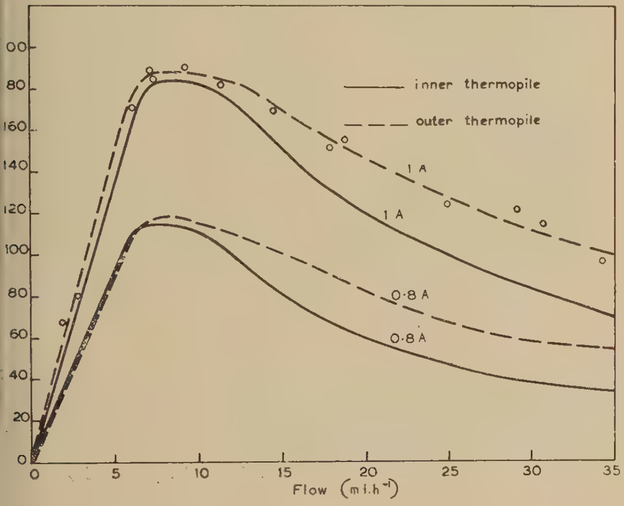

Fig. 2. Calibration curves for the flowmeter (0·8 A and 1·0 A refer to the currents used in the heater wire). Experimental observations are shown (°) on one curve. Measurements are repeatable to within about 5%

(*a*) by diverting a small part of the fluid flow, and observing whether or not the measured e.m.f. increases or decreases;

(*b*) by making readings in succession at two prescribed values of the heating current;

(*c*) by making readings in succession on two systems of thermocouples, one being very close to the heater wire and one being farther away.

The present instrument carries two systems of thermocouples, so that the third method may be used if the first two methods are both inappropriate.

CALIBRATIONS AND TESTS

To calibrate this instrument, it was connected to a water-filled tube blocked by a suitable porous plug, and leading to a reservoir containing water at room temperature, the height of which could be adjusted to produce different rates of flow. It was found necessary to make the outlet tube from the instrument discharge into a half-full beaker of water. If drops were allowed to form at the outlet, surface tension forces caused the flow to fluctuate.

The calibration curves plotted in Fig. 2 show two régimes. At higher rates of flow, the output falls as the flow increases. This is to be expected because, with a given heat output from the wire, the water temperature should be inversely proportional to its volume flow. But conduction through the water, tending to equalizing temperatures at the two junctions, is evidently significant because the outer thermopile shows a larger output indicating a larger temperature difference. At low flows, conduction has control, and the output tends linearly to zero as the flow decreases. This régime is the useful part of the calibration curves.

The output appears to be linearly proportional to the power used in the heater wire. The output is not critically dependent on the spacing of the junctions, which makes for ease of manufacture.

Because the instrument is intended for use in thermal regions of New Zealand, further tests were made in which the instrument and the water fed to it were hotter than before. At a temperature of 55° C, the calibration was unchanged; at a temperature of 72° C, there were continual fluctuations in the measured e.m.f. These fluctuations were probably caused by steam bubbles being formed on the surface of the heating wire.

All air must be expelled from the instrument if its action is to be reliable. Tests showed that the instrument is not sensitive to orientation.

USE IN THE FIELD

Flows through permeable soil can be measured by using a collector of suitable area that traps a portion of the flow and guides it through the instrument. In the river-bed measurements mentioned above, the bottom was cut away from a domestic pressure-cooker and the instrument attached to the steam vent in the lid. This apparatus was pressed down beneath the water into the sandy river bed. After allowing time for the seepage flow to re-establish itself, measurements were made with the aid of a small 6 V battery, an ammeter, a sliding resistor, and a potentiometer accurate to 10 μV. The seepage from each square centimetre of the area of sand under the instrument proved to be about 0·005 ml.h^{-1} with a probable accuracy of ±20%. The apparatus proved quite portable and sufficiently rugged for field work.

POSSIBLE MODIFICATIONS

The instrument is best used on the steep part of its calibration curves, that is, at flows less than 6 ml.h^{-1} for the present instrument. However, by making the flow channel wider, the instrument could be adapted to measure larger flows.

In future flowmeters, more thermocouples could be incorporated so as to increase the output e.m.f. and make the instrument more sensitive.

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* The ribbon was obtained from the A.S.H.V.E. Research boratory, 7218 Euclid Avenue, Cleveland 3, Ohio.

ACKNOWLEDGEMENT

The apparatus was built and calibrated during a University vacation with the guidance of Mr. R. F. Benseman of the Dominion Physical Laboratory.

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Resistance thermometer spear for field measurement

By A. C. Jason, B.Sc., Ph.D., A.Inst.P., and A. Lees, Torry Research Station, Aberdeen

[*Paper first received* 22 *December*, 1958, *and in final form* 19 *January*, 1959]

The instrument described measures temperatures in the range −30° to +70° F with an accuracy of ±0·2° F. The sensitive portion consists of a copper wire spiral enclosed in a length of hypodermic tubing; the resistance is measured on a Wheatstone bridge. The instrument is cheap, reliable, robust, and self-contained.

There are many field applications in which it is desirable to measure temperatures within materials to an accuracy comparable with that of a good mercury-in-glass thermometer. The requirements of an instrument for making such measurements are that it should be portable, robust and suitable for remote reading. While the accuracy of thermocouple measurements certainly suffices under normal conditions, it is necessary to employ a fairly sensitive galvanometer. As a rule, portable thermocouple potentiometers, incorporating taut suspension galvanometers of a somewhat lower sensitivity, sacrifice accuracy for robustness. They suffer from the further disadvantage that they cannot be used under conditions of vibration or aboard a moving vehicle. Commercially available resistance thermometers on the other hand, while having the desired accuracy, are cumbersome and expensive.

The instrument to be described was devised initially to measure the temperature distribution in fish in bulk aboard fishing vessels, on road and rail vehicles and at every stage along the distribution chain. It was considered that resistance thermometry offered the most promising method for making point measurements rapidly and reliably under the varied and frequently adverse conditions encountered. Suc an instrument had also to be cheap, reliable and able to b operated by unskilled personnel. This has been achieved b constructing a probe or spear consisting of a short length o hypodermic tubing containing a copper resistance element a one end, and an associated measuring bridge incorporati a heavily damped null-indicating meter.

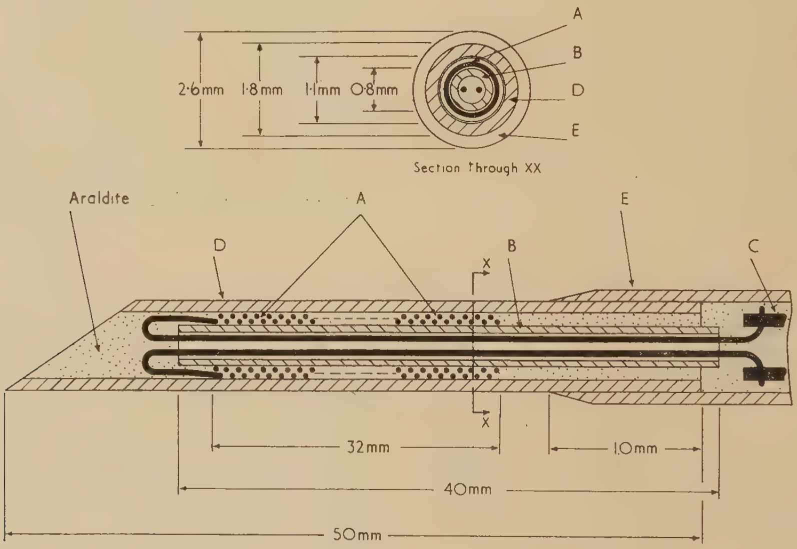

Fig. 1. Sectional view of resistance thermometer spear

The construction of the spear is shown in Fig. 1. I consists of a length of 46 s.w.g. Bicelflux self-fluxi enamelled copper wire *A* (by British Insulated Callende Cables Ltd.) wound in two layers, each 32 mm long, roun a hollow glass former *B*, giving a resistance at room temperature of about 11 Ω, the ends of the wire being taken through the inside of the former and soldered to 26 s.w.g. enamelle copper leads *C*. This element is cemented with Araldite int a stainless steel hypodermic tube *D*, inserted a short distanc into the bore at one end of a stainless steel tube *E* enclosin the copper leads *C*. The ends of the copper leads are soldere to terminals within a Tufnol handle on the opposite end o the larger tube. The glass former is drawn from standar Pyrex tubing. A photograph of a typical spear with a associated measuring bridge is shown in Fig. 2.

copper element was preferred to one of nickel because, the desired accuracy of measurement in the range of perature concerned, the resistance-temperature law for kel departs considerably from linearity. Platinum was sidered as an alternative material but it offers no antage over copper in this respect, while at the same time s not readily available in the form of fine enamelled wire. elflux wire was chosen because the self-fluxing property of enamelled covering obviates the difficulties of baring and aning before soldering the ends to the 26 s.w.g. wires.

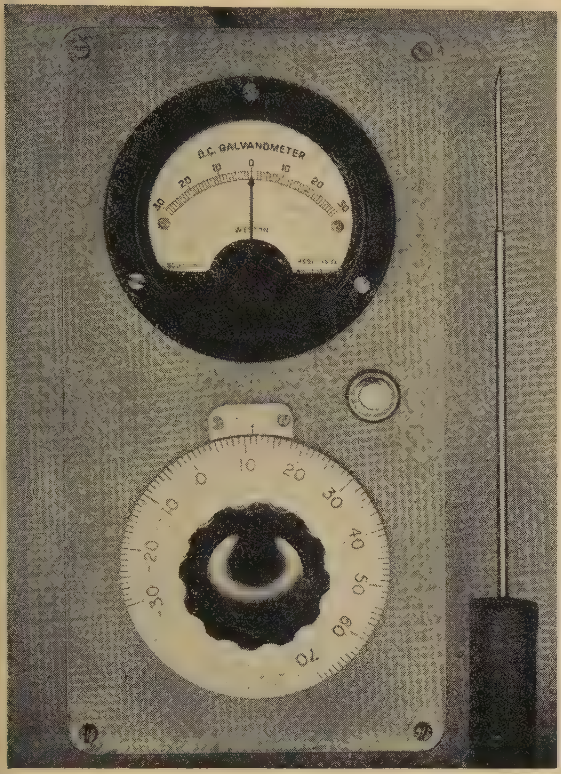

Fig. 2. Resistance thermometer spear with associated portable bridge

A flexible coaxial cable connects the thermometer element the bridge. It consists of an inner conductor of seven rands of 36 s.w.g. copper wire and an outer conductor of rty-eight strands of braided 38 s.w.g. copper wire. The ble introduces a total series resistance of 0·11 Ω/m at om temperature.

The bridge (Fig. 3) was designed as a portable self-contained strument to measure temperature in the range −30 to -70° F with an accuracy of about ±0·2° F, though by itable calibration other ranges are readily available. The nsitivity of balance is limited by the choice of galvanometer d by the maximum current that may be permitted to flow rough the element without producing a noticeable rise in mperature. It was found that a normal wire-wound 100 Ω otentiometer R_2 (by Colvern Ltd.) was sufficiently linear to ve direct temperature indication, when used with an graved scale on which the divisions were evenly spaced. he scale was engraved in such a way that a short length of e track of the potentiometer remained unused at each end the scale. The function of the preset potentiometers R_3 d R_6 are to provide an adjustment so that each scale vision corresponds to 1° F. Initial settings are made by mersing the spear to a depth of 12½ cm alternately in two baths of known temperature and successively adjusting both R_3 and R_6, with the scale attached to R_2 set at the appropriate value at each temperature until no further adjustment is required. The galvanometer which was selected has a resistance of 75 Ω and a sensitivity about zero of 1·3 mm/μA.

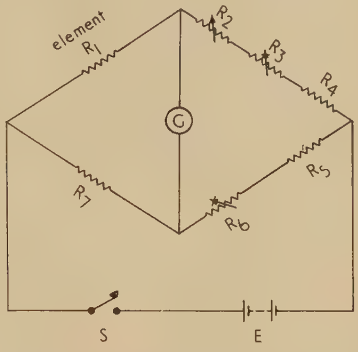

Fig. 3. Arrangement of bridge for direct indication of temperature

$R_1 \sim 11\ \Omega$ (element)
$R_2 = 100\ \Omega$
$R_3 = 50\ \Omega$
$R_4 = 300\ \Omega$
$R_5 = 330\ \Omega$
$R_6 = 50\ \Omega$
$R_7 = 10\ \Omega$
$E = 4{\cdot}5$ V
G = Sangamo Weston type S 20 galvanometer, 75 Ω
S = push-button switch, normally biased off

It is mounted on the top panel of the small box containing the rest of the components, including the 4·5 V torch battery.

Although the elements for a number of similar instruments were constructed from commercial purity copper wire, the calibration did not vary detectably over a period of months. No effort was made to produce elements of similar resistance at room temperature, though no doubt this could easily be done.

Errors resulting from resistance changes in the 26 s.w.g. lead wires in the spear at various depths of immersion were calculated to be within ±0·1° F in the range −30 to +70° F. Fluctuations in the resistance of a given length of flexible cable imposed a limit on the range of ambient temperature in which the instrument could be operated with the desired accuracy. For example it was estimated that, for an accuracy of ±0·1° F, a metre length of cable permitted variations of ±10° F in room temperature to take place, thus giving an overall accuracy of ±0·2° F in this range.

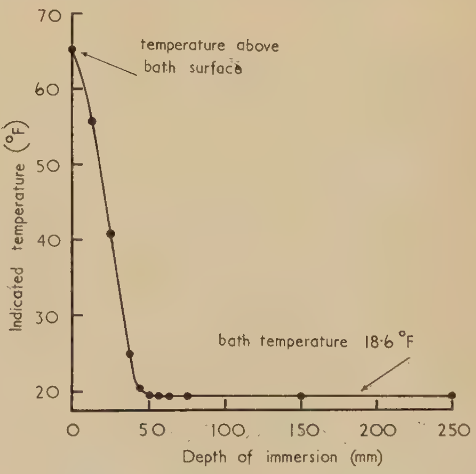

Fig. 4. Indicated temperature as a function of depth of immersion of tip of spear in acetone bath at temperature of −18·6° F

In Fig. 4 the indicated temperature plotted for a typical spear as a function of the depth of immersion of its tip in vigorously stirred acetone shows that, for complete immersion of the element, errors due to stem conduction are negligible. The thermal time constant of the spear in well stirred acetone was estimated to be about one second.

Continual use of several similar instruments under severe conditions over a period of several months did not lead to any mechanical or electrical troubles, such as breakage of strands of wire in the flexible leads or changes of calibration after repeatedly thrusting the spear into frozen fish. The robustness of both the spear and the bridge was such tha they survived impact on concrete floors when accidentall dropped from a height of a few feet on several occasions The accuracy of the instrument was found to be unimpaire on subsequent calibration.

ACKNOWLEDGEMENTS

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Vacuum fatigue-apparatus

By N. J. Wadsworth, Ph.D., Royal Aircraft Establishment, Farnborough, Hants

[*Paper received* 17 *December*, 1958]

An apparatus is described in which it is possible to anneal specimens in vacuo and then fatigue them in vacuo or in any desired atmosphere without intermediate exposure to air. Annealing temperatures of up to 800° C are used and extension up to 1000 °C is possible. The specimens are flat sheets. An electromagnetic drive is used to fatigue them in reversed bending between constant strain limits at 100 c/s. Both extremes of the movement of the specimens are monitored optically and a servo system keeps them constant in spite of changes in the modulus or damping of the specimens during the test. An automatic cut-out stops the test as soon as a large crack appears in the specimen. Some typical results are shown.

1. INTRODUCTION

In experiments on the fatigue of metals it is sometimes desirable to conduct the experiment in a controlled gas atmosphere or in vacuo. The practice of surrounding part of a conventional fatigue machine by an enclosure has the disadvantage that the specimen, after its final preparation, is exposed to air while being fixed in the machine. This paper describes an apparatus in which the fatigue specimen can be annealed free of all constraint in vacuo or a controlled atmosphere and then fatigued in any desired environment without exposing it to air between the two operations.

An electromagnetic drive is used for the fatigue test as this does not involve any moving parts entering the vacuum system with associated risk of leaks. Both extremes of swing are monitored continuously thus preventing soft specimens from creeping to one side.

2. DESCRIPTION OF APPARATUS

2.1 *General.* The apparatus is shown in Fig. 1. One end of the specimen *A* is fixed to a stainless steel tube *B*, and a piece of soft iron with a thin vane is bolted to the free end. The whole is surrounded by a silica tube *D* which is connected to a vacuum system. The lower end of the circular silica tube is fused to a rectangular section shown in more detail in Fig. 2. As will be seen later this allows the magnets to be placed close to the specimen and also allows the light beams used for control to pass through flat windows. An oil diffusion pump backed by a rotary pump is used and this, together with a liquid nitrogen trap and the use of large diameter ($\nless 2$ in.) connecting tubes, enables a pressure of 10^{-5} mm of Hg to be obtained fairly quickly. Gases can be admitted through the tube *E* which releases them close to the specimen.

To anneal the specimen a furnace is placed around the lower part of the silica tube. There is no constraint on the lower end of the specimen so the specimen is free of all stress apart from that due to its own weight. The annealing temperature is limited to 800° C. Above this temperature volatile metals evaporate from the stainless steel. The silica itself could withstand 1000° C with a vacuum inside and the operating temperature could be increased to this level if the stainless steel were replaced by a more suitable metal.

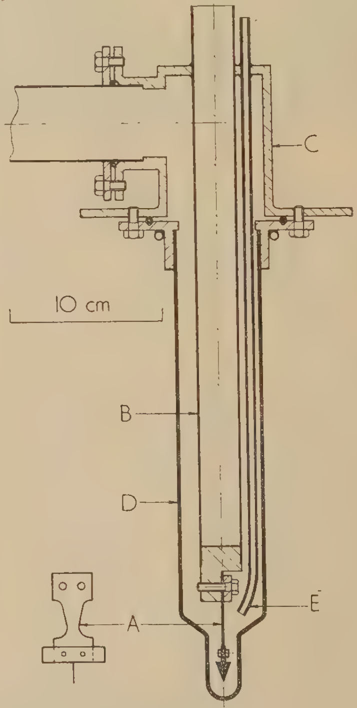

Fig. 1. The fatigue apparatus

The specimen *A* is attached to a stainless steel tube *B* and surrounded by a silica tube *D*. Gas can be admitted through tube *E*.

or the fatigue test the furnace is removed and an electro- gnet placed on each side of the flat end of the silica. The gnets are supplied with current from two different phases he 50 c/s a.c. mains. This produces a force on the iron ch varies sinusoidally at 100 c/s. The force needed is t small by adjusting the mass on the bottom of the speci- n to make the system approximately resonant. Fig. 2

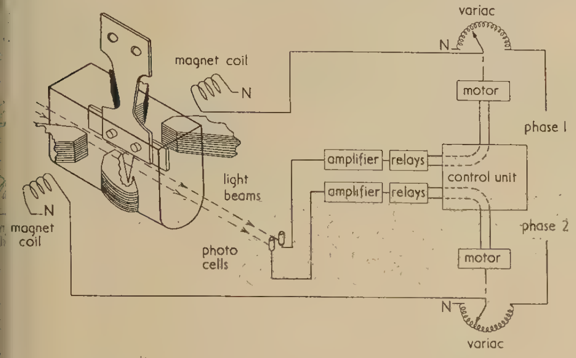

Fig. 2. Block diagram of the apparatus

ws how the amplitude of the vibration is controlled. The extremes of the specimen movement are monitored by beams of light which are partially interrupted each cycle the vane attached to the specimen. Each beam falls on a otocell. The signal from each photocell is amplified and lied to two relays. If the signal is too big one relay closes t energizes a motor driving the Variac feeding the appro- ate magnet. This reduces the current and so the amplitude swing. Conversely if the signal is too small the other y operates and the current in the magnet is increased. ce each extreme of the swing is monitored in this way h the amplitude and the mean position of the vane are t constant. The control unit connects the relays to the riac motors and also contains various over-riding switches manual control of the Variac motors, a cut-out, etc.

The specimen is shaped to give a uniform surface strain r the central portion on which observations are made Fig. 1). A small catch (not shown in the figures) prevents lower end of the specimen from touching the silica should amplitude be too large or the specimen bend to one side to malfunctioning of the apparatus.

The construction of the various parts of the apparatus will described in more detail.

.2 *The magnets.* The magnets are constructed as shown Fig. 3. The coils and core are designed to enable the iron on the bottom of the specimen to be saturated easily with a gap of over 1 cm between it and the magnets. The core is made from a 3·8 cm stack of standard "U" transformer laminations. The thickness is reduced to 1·9 cm at the poles to concentrate the field.

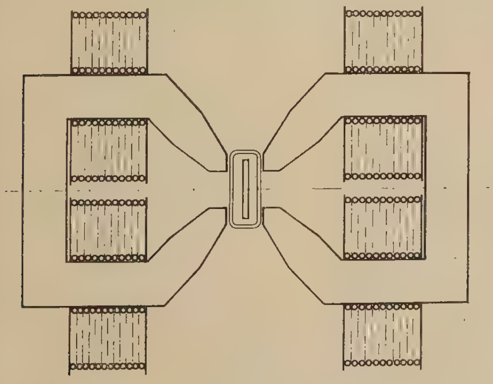

Fig. 3. The electromagnets
(Scale ×0·185)

Each coil consists of 210 turns of 12 s.w.g. d.c.c. copper wire, the two coils on each magnet being connected in series. Currents of between 3 and 11 A r.m.s. (corresponding to between 50 and 150 V across each magnet) are used.

The force produced by one magnet, with 10 A flowing, on a piece of iron 1 cm × 4 cm × 1·2 mm (a typical size needed to tune the specimens to resonance) is about $2 \cdot 1 \times 10^5$ dyn at a distance of 1 cm or $1 \cdot 3 \times 10^5$ dyn at 1·5 cm. Forces of this order are adequate.

2.3 *The optical system.* The basic optical system is shown in Fig. 4. The biconvex lens forms images of the filaments of the lamps L_1 and L_2 at I_1 and I_2 in the plane of vibration of the vane on the end of the specimen. For convenience the light rays are folded by a 45° mirror at M. The lamps are mounted so that the distance between them can be adjusted while keeping them equal distances from the optic axis. The light from the images falls on two photocells PC_1 and PC_2. The movement of the vane needed to interrupt the light beam completely is kept small by using lamps (6 V 6 W) with small straight filaments and by the 6 : 1 reduction in size produced by the lens. The sensitivity can be adjusted by rotating the lamps to alter the angle between the length of the image of the filament and the edge of the vane. The small size of the photocells (sensitive region 3 mm in diameter) means that small errors in focusing have little effect on sensitivity. In practice the sensitivity is set so that an error of more than 0·05 mm in each extreme position of the vane is corrected.

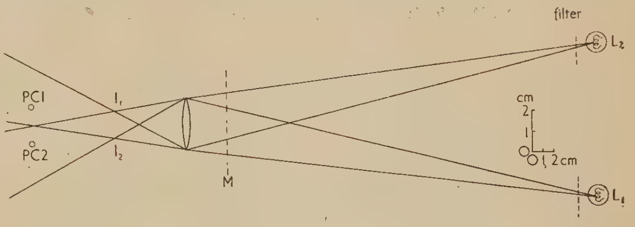

Fig. 4. The optical system
In practice the light beams are folded by a 45° mirror at M.

Filters which transmit the near infra-red (to which the photocells are sensitive) while absorbing most of the visible light are placed in front of the lamps to prevent dazzle when observing the vane visually to determine the amplitude of vibration (see section 3).

2.4 *The photo-cells and the signal amplifier.* Photo-emissive photocells are unsatisfactory since they are too large to allow the vane to be seen between them and also because they are seriously affected by the strong alternating magnetic field. Phototransistors are smaller and are unaffected by magnetic fields. Two OCP71's are used and prove satisfactory.

The lamps are run from a smooth d.c. supply to ensure constant brightness. The signal from each photocell consists of a steady current with momentary reductions, lasting <1 ms, occurring at a rate of 100 pulses per second. This signal is amplified by an a.c.-coupled amplifier (thus removing the effect of any stray illumination of the photocells) and the signal is rectified. The resulting d.c. signal, which is a measure of the amount of light interrupted by the vane, is

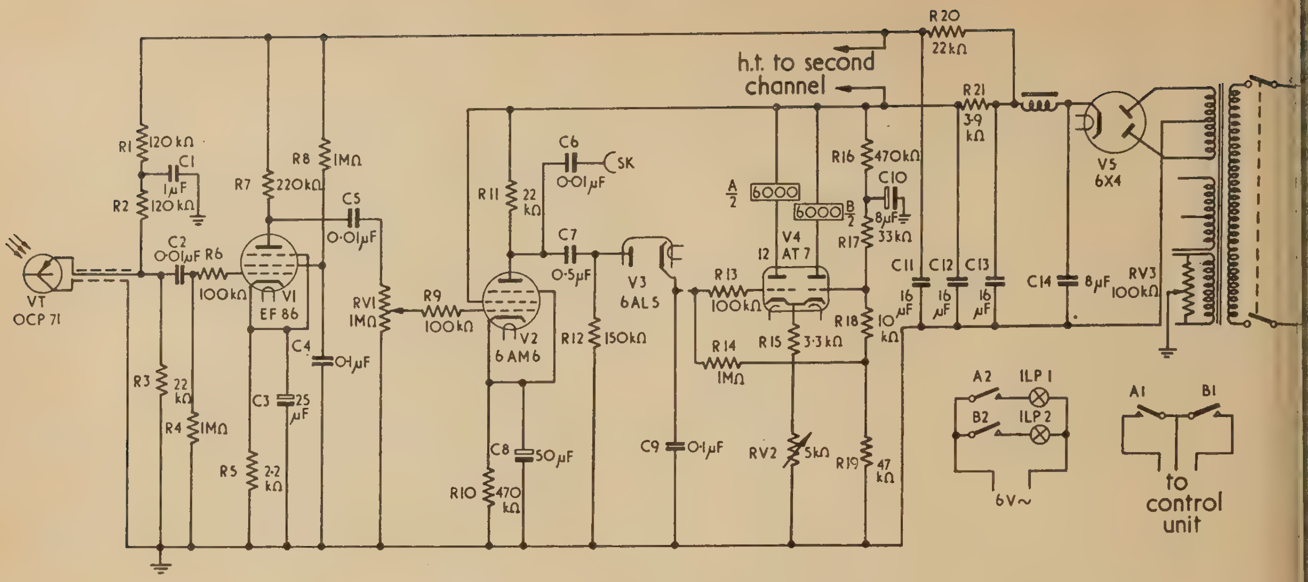
VT
OCP 71
R1 120 kΩ
C1 1μF
R2 120 kΩ
C2 0·01μF
R6 100 kΩ
R3 22 kΩ
R4 1MΩ
R5 2·2 kΩ
R7 220kΩ
R8 1MΩ
V1 EF 86
C3 25μF
C4 0·1μF
C5 0·01μF
RV1 1MΩ
R9 100kΩ
R11 22 kΩ
C6 0·01μF
SK
C7 0·5μF
V2 6AM6
C8 50μF
R10 470 kΩ
R12 150kΩ
V3 6AL5
C9 0·1μF
h.t. to second channel
R13 100kΩ
R14 1MΩ
R15 3·3 kΩ
RV2 5kΩ
A/2 6000
6000 B/2
V4 AT 7
R16 470kΩ
C10 8μF
R17 33kΩ
R18 10 kΩ
R19 47 kΩ
R20 22kΩ
R21 3·9 kΩ
C11 16 μF
C12 16 μF
C13 16 μF
C14 8μF
V5 6X4
RV3 100kΩ
A2
B2
ILP 1
ILP 2
6V~
A1
B1
to control unit

Fig. 5. Circuit diagram of the amplifier

applied to a long-tailed pair with a relay in each anode circuit. One relay closes if the signal is too large and the other if it is too small.

The complete circuit of one amplifier is shown in Fig. 5. RV_1 controls the amplitude of the signal applied to the long-tailed pair (V_4). RV_2 adjusts the total current through the relays and hence the change of signal needed after one relay has opened before the other closes. Indicator lights ILP_1 and ILP_2 show when the relays close. An oscilloscope can be connected to the socket *SK* to assist in checking operation.

The amplifiers for the two photocells are identical and are fed from a common power supply also shown in Fig. 5.

2.5 *The control unit.* The control unit is used to interconnect the various units and to provide manual control for the Variac motors. It also houses a cut-out and a system for moving the motors in small steps. The latter is necessary as the motors used have no brakes and so continue turning for a short time after the current to them is switched off. This overshooting could cause hunting. To prevent this the driving current is applied in a series of pulses each sufficient to cause the wiper on the Variac to move about 1 turn and with sufficient time between pulses to allow the motor to come to rest. About 2 pulses per second are used.

The cut-out is designed to switch the machine off as soon as a large crack appears in the specimen. A crack lowers the

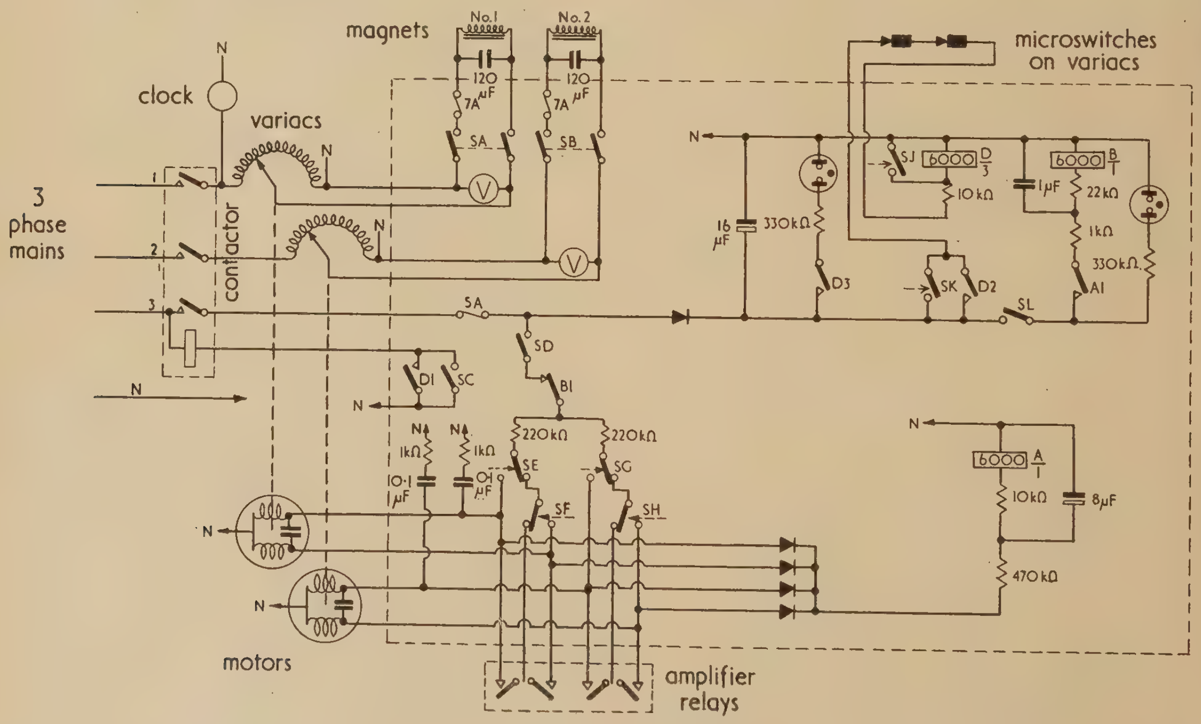
magnets
No.1
No.2
120 μF
7A
SA
SB
clock
N
variacs
3 phase mains
1
2
3
contactor
V
SA
SD
B1
D1
SC
1kΩ
0·1 μF
220kΩ
SE
SG
SF
SH
motors
amplifier relays
microswitches on variacs
16 μF
330kΩ
D3
SJ
6000 D/3
10kΩ
1μF
6000 B/1
22kΩ
1kΩ
330kΩ
A1
SK
D2
SL
6000 A/1
10kΩ
8μF
470kΩ

Fig. 6. Circuit diagram of the control unit

ng constant of the specimen and also increases the ıping. Thus more current is required in the magnets to ntain the vibration. Microswitches are mounted on the iacs and operate the cut-out when either wiper has ıted more than a predetermined amount from its initial ition. The cut-out also operates if one or both lamps ɪe to work as this results in loss of signal from the cor- ɔonding photocell and so causes a movement of the iac wiper. The cut-out also operates if the mains supply s. An electric clock records the duration of the test.

he complete circuit of the control unit is shown in Fig. 6. tches *SE*, *SF*, *SG* and *SH* allow the motors to be energized ıually and override the relays in the amplifier. Relays *A* *B* with their associated circuits provide the pulsed current he motors when switch *SL* is closed. Arcing at the relay tacts is suppressed by series resistors and by a resistor capacitor connected across each motor. Relay *D* works cut-out by de-energizing the contactor *via* contact D_1 can be overridden by switch *SC*. Switches *SJ* and *SK* w relay *D* to be energized and de-energized as required. neon lamps show when the pulser is switched on and ɜn relay *D* is closed.

he voltage outputs from the Variacs are indicated on a r of voltmeters which enable changes in specimen reson- e to be followed. The voltmeters also enable the voltage be checked before the magnets are connected. A power tor capacitor is connected across each magnet to reduce current taken to within the rating of the Variacs.

3. STRAIN DETERMINATION

he amplitude of movement of the bottom of the specimen letermined by observing a scale on the vane with a micro- pe. The place where the movement is equal to the width the vane is clearly distinguishable and is independent of irregularities in the silica windows through which the ervations are made. These irregularities would invalidate direct measurements of amplitude made from outside or use of calibrated lamp movements. There is some move- nt of the lower end of the tube *B*, to which the specimen ixed so the relation between vane movement and surface ıin in the specimen has to be determined experimentally each specimen size and material. This is done by using ctrical resistance strain gauges stuck on a dummy specimen igued under standard conditions. As far as is possible all cimens of one type are made of the same thickness. The all variations ($<7\%$) which do occur are allowed for by uming that the deflexion is proportional to the product of ıin and thickness. This assumption causes only small ors for the range of thickness used and does not add ɔreciably to the scatter.

4. OPERATION

When an annealed specimen of a pure metal is to be igued it is necessary to increase the amplitude of vibration wly to allow the specimen to harden gradually. This is ne by setting the lights close together and making the machine control at a low amplitude. The lamps are then slowly moved apart allowing the amplitude to increase. If this is done too quickly the servo system is unable to correct quickly enough any tendency of the specimen to creep to one side. In practice about 10^4 cycles are needed to attain full fatigue strain on annealed copper whereas annealed aluminium, which creeps more easily, needs about six times as long. When the full amplitude is reached there is at first a tendency for the specimen to creep slightly first to one side and then, as this is corrected, to the other. Copper soon hardens sufficiently for this to stop (or only to occur infrequently) but aluminium takes longer. With harder metals such as aluminium alloy creep is very much less serious and the apparatus is always stable.

5. TYPICAL RESULTS

Fig. 7 shows some results obtained with this machine and indicates the experimental scatter. Oxygen-free high-conductivity copper specimens were electropolished and then annealed in the machine at 800° C in a vacuum. They were then fatigued, all at the same strain, in various pressures of air. In some cases the air pressure was obtained by admitting the required amount of air through the tube *E* and then sealing off. In other cases the pumps were left on and a suitable flow of gas admitted through the tube *E*. It made no apparent difference to the results which method was used. The fatigue life increased considerably as the pressure was reduced. Similar observations are being made on other metals. The results for copper, aluminium and gold are being published.*

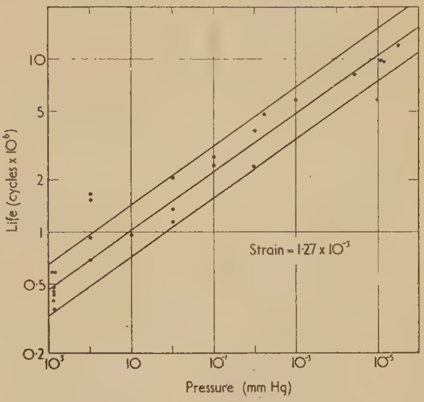

Fig. 7. The variation of the fatigue life of oxygen-free high-conductivity copper with air pressure

6. ACKNOWLEDGEMENT

Thanks are due to Mr. H. W. Sumner for constructing the silica tube.

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* *Phil. Mag.*, **3**, p. 1154 (1958).

Demountable vacuum seal for operation at temperatures from −188° C to 800° C*

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A new type of metal gasket vacuum seal is described which depends on a surface-friction effect instead of compression, which is the basis of most seals described so far. Tests have proved the effectiveness of the seal for repeated cycling between −188 and 800° C on flanges of 3 and 5 in. diameter and on a $\frac{1}{2}$ in. vacuum union. The materials used include mild steel or stainless-steel flanges with flat gasket sheets of soft copper, iron, stainless steel or nickel. Other metal gasket vacuum seals are briefly reviewed and the mechanism of sealing is discussed. A table of recommended dimensions for flanges from 3 to 12 in. diameter is also presented.

Vacuum seals to withstand high temperatures (e.g. 500° C) necessitate the use of materials which, at high temperatures, have a low vapour pressure, do not decompose and retain their mechanical properties. These conditions preclude the use of the more conventional forms of vacuum gasket materials such as rubber, waxes, neoprene and P.T.F.E. To satisfy the above conditions, the vacuum seals must, in general, be constructed in metal, those metals such as lead, cadmium, zinc, sodium, indium, etc., which melt or have comparatively high vapour pressures at the temperatures being excluded. Materials used in various seals described include copper, iron, steel, aluminium and nickel.

The general form which such seals take is that of a soft material clamped between two harder surfaces, such as a soft copper gasket clamped between two flanges of steel, one of which has a raised knife edge or semi-circular projection as in Fig. 1(*a*) or a copper or gold gasket having a diamond or circular section clamped between two plain flanges as in Fig. 1(*b*). Aluminium wire as a gasket has properties which render its sealing mechanism different from other forms of wire gaskets.(1) Several such seals have been described.(1–12) However, as soon as the temperature of the seal is raised or lowered, differential expansions or contractions between flanges, gaskets and bolts come into play and, unless allowance is made for these in the seal construction, the seals will leak.

In order to overcome the effects of differential expansion, a number of arrangements have been used, depending on:

(*a*) Equal or nearly equal expansions throughout the temperature range of flanges, bolts and gasket materials as in Fig. 1(*b*) and (*c*); or

(*b*) The use of a spring member intended to maintain sealing pressure over the temperature range when differential expansions would tend to lessen the pressure. This spring can be in two forms. It can consist of either a separate ring bolted to the top flange with a spacer between flange and ring located between each pair of bolts(3) as in Fig. 1(*d*) or a special flange which has been undercut around its circumference to provide a spring action when clamped,(7) as in Fig. 1(*e*).

It has been found in tests carried out in this laboratory that most of the seals described in the literature leaked after a few quick temperature cycles. The new flange seal is shown in Fig. 2 in the open and closed position. The gasket, of thin material (0·005–0·010 in.), lies between the surfaces of a male cone on one flange and a mating female cone on the other flange.

The gasket is initially flat and only when the flanges are bolted together does it take up its final shape as shown Fig. 2(*b*). The use of a gasket pre-formed to its final sha is an advantage in some instances (e.g. on vertical seals) bu in general, the flat gasket is more satisfactory as it may

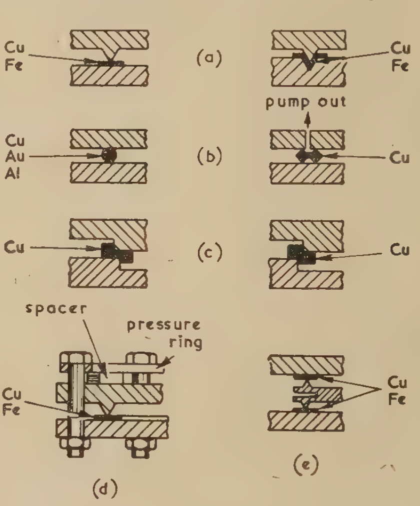

Fig. 1. Previous metal gasket seals

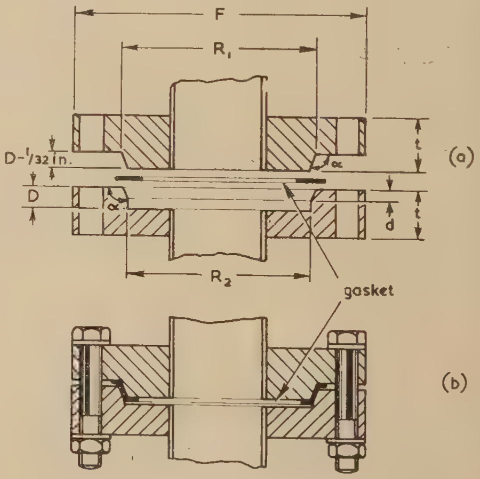

Fig. 2. Flange seal, (*a*) open, (*b*) closed

cut from any convenient flat sheet. The sealing surfaces ar finely machined and need no polishing treatment. It i advisable to remove all sharp edges which may produc score marks on the gasket during the initial tightening of th flanges.

The forming of the seal takes place in two distinct opera ns. Firstly, the forming of the gasket to the cone shape achieved by a drawing operation after which further itening of the bolts forms the vacuum seal.

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* Subject of Brit. Pat. Application No. 19253/58.

'he final pressure required to form the seal varies with the ar strength of the gasket material. With the number and of bolts specified in the table, no difficulty was experienced forming the seal. The nature of the forces forming the l make necessary the use of grub screws to force the flanges irt after the clamping bolts have been removed. Three four such screws spaced around the circumference of one he flanges are sufficient.

EXPERIMENTAL RESULTS

i) *Tests on continuously pumped seals.* Tests were carried on seals with flanges of 3 and 5 in. diameter (sealing meters, 2$\frac{1}{16}$ and 3$\frac{11}{16}$ in.) over a temperature range m room temperature to 500° C, with flanges of mild steel l stainless steel and with gaskets of copper, soft iron, kel and stainless steel. The dimensions of the seals are en in the table. All the seals except the one comprising stainless-steel gasket with mild-steel flanges were comtely leak-tight as tested on a palladium-barrier leak ector (sensitivity, 10^{-5} lusec), when cycled between room iperature and 500° C. The leak tests were carried out ile the seals were hot, as well as before and after temperae cycling. In most tests the maximum temperature was ched in approximately one hour, and cooling was carried by blowing compressed air on to the seal. It is felt that se rates of heating and cooling are faster than are likely be met in practice. During the tests, the inside of the ls were continuously pumped. After baking, the seals ild be broken without difficulty. For this purpose, three ib screws were used in tapped holes provided on one of flanges on the same pitch circle diameter as the clamping lts, and with the same thread diameter. In one instance, bolts were removed and the seal cycled up to 500° C, er which it was still leak tight.

With the stainless-steel gasket with mild-steel flanges, leaks the order of 10^{-3} lusec were observed when the temperae reached 400° C. It was difficult to make this seal tially, and examination of the gasket after its use suggested it it had work-hardened to such an extent during the ming operation that it merely scored the mild-steel cone faces whereas surface shear in the gasket was practically n-existent.

(ii) *Tests on 3 in. diameter flange seal after subjection to h and low temperatures.* A test seal was made using two ld-steel flanges and a soft-iron gasket. No tubes were nnected to the centre of either flange. The gasket seal was k-tested to a sensitivity of 10^{-5} lusec. Having been oved leak-tight initially, the seal was placed in liquid air verage temperature 188° C) and allowed to reach the nperature of the liquid. It was then removed and allowed attain room temperature, this process being accelerated by mersion in water. No leak was located.

The test seal was then placed in a vacuum furnace and ised quickly to a temperature of 800° C and cooled slowly ien it showed no leak. Further tests using a massectrometer leak detector showed that the seal was tight to specification better than 10^{-6} lusec. Having been raised this high temperature, the flanges were difficult to take art. It was found that the soft-iron gasket had been elded to the mild-steel conical surfaces. It is felt therefore at, because of the nature of the seal (which entails local ld welding), the combination of pressure and temperature at 800° C welds so effectively that the upper limit of temperature for mild-steel flanges with soft-iron gaskets must be fixed at approximately 500° C. In similar tests carried out using stainless-steel flanges with a stainless-steel gasket, it was found that the seal could be easily broken after having been raised to 800° C. This test seal was raised to 800° C in air by r.f. heating. Tests before and after heating showed no leak to a sensitivity of 10^{-5} lusec.

(iii) *Tests on vacuum union.* Fig. 3 shows a union seal employing the same principle as the flange seal. The tests were performed on a union connecting two $\frac{1}{2}$ in. i.d. tubes. Dimensions for larger and smaller sizes will be to scale. The union was made from mild steel, and gaskets of copper and soft iron were used during tests. Other materials can, however, be used for the union (e.g. stainless steel, nickel or chromium-plated mild steel) with gasket materials as given in the table. The seal was made by the straightforward tightening of the union nuts. To break the seal, a flange was welded to the union liner behind the union nut.

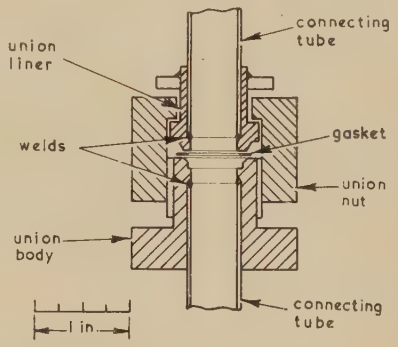

Fig. 3. Union seal

The union made was leak-tested to a sensitivity of 10^{-5} lusec before and after immersion in liquid air and also before and after raising to 500° C. No leak was detected, and the seal was readily broken.

PHYSICAL MECHANISM OF SEALING

The action of clamping a flat, soft-metal gasket between a knife edge and a plain flange, or a thick, soft-metal gasket with sharp edges (e.g. a diamond-section copper ring between two plain flanges) is to cause the soft gasket material to flow and fill in the crevices in the surfaces on the flanges which are left after machining and polishing. An unfilled scratch of only $0{\cdot}2\,\mu$ depth connecting the atmosphere with the vacuum would give a leak of 10^{-7} lusec.(13) This flowing action causes small surface-friction forces across the contacting surfaces. However, the principal sealing action comes from the large forces acting on the knife edge (or edges) which deform the gasket mechanically and cause it to flow locally and fill in surface irregularities.

The new seal does not rely on compression—which must obviously still exist—but on surface shear brought about by the large frictional forces involved. Two clear stages exist in the making of the seal:

(1) The gasket is formed, by a drawing operation, to the shape of the cone surface.

(2) Further pressure from the bolts produces the surface-shearing action which forms the vacuum seal.

The force required for stage (1) is very much smaller than that required for stage (2).

It can readily be seen that surface-friction effects are principally responsible for maintaining the vacuum seal, because the seal still remains perfectly good when the bolts are removed from the flanges. The drawing operation may expose fresh surfaces on the gasket which assist in the sealing action. However, the use of pre-formed gaskets appears to have no deleterious effects.

The independence of the seal to temperature changes is attributed to two factors:

(1) The flanges, being of the same metal, expand and contract radially by equal amounts, thereby maintaining the frictional forces across the sealing surface.

(2) The frictional nature of the seal ensures that differential expansions between bolts and flanges are now of no consequence.

The advantage of this type of seal becomes more apparent if one considers that adhesive forces produced in sliding friction are much greater than those produced by pressures normal to the sealing surfaces. The reason for this is that surface-friction forces break up oxide and other surface contaminants, thus permitting local welding between pure metal surfaces.(14) Adhesion or local welding using pressures normal to the sealing surfaces can only be effective with freshly cleaned surfaces such as those used in cold-welding techniques. For this reason, many of the seals described in the literature have to undergo elaborate cleaning and polishing procedures before assembly.

The choice of the angle α [Fig. 2(*a*)] of the cone is governed by the necessity to maintain the surface shear forces as large as possible. The component of the force produced by the bolts which gives surface shear is equal to the product: *bolt force* $\times$ *cos* $(\alpha - 90°)$. This component is a maximum when α is 90°, which is an impossible mechanical condition. The angle α, therefore, should be as near 90° as possible, consistent with reasonable machining tolerances. An angle of 100° was found satisfactory in the tests performed.

CONCLUSIONS

For a particular joint using a given flange material and size, it is necessary to consider carefully the flange thickness, the bolts required, the bolt spacing, the pitch circle diameter of the bolt holes, the gasket thickness, the angle of the cone and the gasket size. The table gives dimensions of typical seals. The figures for the 2½, 3 and 5 in. flanges have been thoroughly tested, and those for the 8 and 12 in. flanges have been estimated on the basis of the results for the smaller flanges. Flange seals of 7 and 10 in. diameter have recently been used successfully in this laboratory, and have been re-made several times using the same gasket.

The work described was initially carried out in order to perfect a seal which could be used in bakeable metal hig vacuum systems, particularly in ultra-high-vacuum applica tions for joining metal valves to ultra-high-vacuum apparatu Other applications are possible. For example, in the recen paper by H. Kronberger,(15) some seals used in the atomic energy industry were described which served over a limite temperature range. These seals were used in systems handlin (*a*) high-pressure water at 350° C, (*b*) liquid metal at 200° and higher and (*c*) liquid nitrogen at −190° C. It is fe that seals of the new type could now cover all thes applications.

The new seal has the following advantages over other seal so far described:

(*a*) No special polishing of the sealing surface is require

(*b*) The sealing surfaces on the flanges cannot easily b damaged by rough handling whereas knife edges ar easily damaged by placing on harder, uneven surfaces

(*c*) The design permits the combination on the same pai of flanges of both a metal gasket and a conventiona O-ring seal for the use on the top flanges of metal liqui air traps for example.

(*d*) Vertical seals are easily made using a pre-formed gaske which, once in position, does not move about whe bolts are tightened or the apparatus is placed i position.

(*e*) The same gasket may be used many times on the sam pair of flanges.

(*f*) A subsidiary clamping arrangement, which can b removed once the seal is made, may be used for situa tions where space or weight is limited.

(*g*) The possible number of temperature cycles is ver large. One such seal used in this laboratory has bee cycled approximately 100 times up to 450° C durin which period it has been re-made about 20 times usin the same gasket.

ACKNOWLEDGEMENT

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Recommended seal dimensions and materials

Flange material: mild steel; stainless steel.
Gasket material: copper; soft iron; nickel; aluminium; stainless steel (for stainless-steel flanges only)
(Use maximum number and size of bolts for soft iron and stainless-steel gaskets)

Maximum tube O.D. (in.)	*Dimensions (in.) referred to Fig. 2(a)*								
	F	*t*	*D*	*d*	R_1	R_2	*Bolt size*	*PCD bolts (in.)*	*No. of bolts*
1	2½	½	⅛	$\frac{1}{16}$	1⅝	$1\frac{19}{32}$	2 BA	2⅛	6
1½	3	½	⅛	$\frac{1}{16}$	$2\frac{1}{16}$	$2\frac{1}{32}$	2 BA–¼ BSF	2½	6
3½	5	⅝	⅛	$\frac{1}{16}$	$3\frac{11}{16}$	$3\frac{21}{32}$	¼–$\frac{5}{16}$ BSF	4¼	6–8
5¼	8	¾	¼	⅛	6	$5\frac{15}{16}$	$\frac{5}{16}$–⅜ BSF	6⅞	8–12
8½	12	1	¼	⅛	9⅝	$9\frac{9}{16}$	⅜–½ BSF	10⅞	12–18
½	½	union	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{11}{16}$	$\frac{43}{64}$	—	—	—

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Bakeable vacuum seals using aluminium-wire gaskets

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The use of aluminium wire as a vacuum seal between steel flanges has been studied. Gaskets made by twisting together the ends of a 22 s.w.g. wire could be baked to 200° C before they leaked on cooling. High temperature working was possible with butt-welded loops of aluminium wire providing the gasket was highly compressed. Such seals did not cold weld but, at baking temperatures above 400° C, the aluminium plastically flowed and adhered to the mating flanges. The "cemented" joint was vacuum tight at low and high temperatures (20–550° C) although the securing bolts became loose after baking. Such a seal leaked only when the aluminium reached its melting point. Information is given on the minimum compression force which must be applied to an aluminium wire in order to form a cemented joint at elevated temperature. Several uses of the aluminium-wire seal are described.

Numerous types of all-metal vacuum seals have been devised or avoiding the presence of rubber gaskets in high vacuum systems. Undoubtedly one of the most simple kinds of seal has been made by clamping indium wire between plane surfaces. Such seals can be heated to a temperature near to he melting point (155° C) of the metal before they leak, providing the indium is initially compressed to form a very thin ribbon. The maximum operating temperature of this eal is, however, too low for effective degassing of metal components by baking. Metal seals have been made using gaskets cut from metal foil on to which are pressed flanges with knife edges. Allowance must be made in the design of such seals for the different thermal expansion of the components. Recently, high-temperature seals have been produced by using gold wire clamped between plane flanges. Gold does not oxidize when baked and it has a similar coefficient of expansion to stainless steel, which is usually employed in the construction of pipelines, flanges, etc. However, gold wire must be highly compressed to obtain a vacuum-tight gasket and, when used between plane surfaces, he two mating flanges may be indented by the wire, thus marring the sealing surfaces. Also, it is costly to use gold n flanges of large diameter. Baldock and Sites* have reported the use of aluminium gaskets in a mass spectrometer but it is not clear how the gaskets were made or if the seals were bakeable.

Recently aluminium wire made from super-purity metal (99·99%) was used as a gasket in a bakeable joint. The early seals were made by twisting together the ends of a length of 22 s.w.g. wire to form a loop which could be clamped between steel flanges. This method produced a seal which was vacuum tight when baked to 200° C but which leaked when cooled after baking to 250° C. It is believed that the aluminium seal failed because, during the baking, the compressed metal had attempted to expand more than the gap between the steel members. Consequently the aluminium wire had flowed and, on cooling, had contracted so that it no longer filled the gap between the flanges.

Tests showed that a leak usually developed where the ends of the aluminium wire had been twisted together. In this region, the thickness of metal undergoing expansion and contraction was nearly twice the thickness of the remaining gasket material. If the flange was again bolted tight after baking to 250° C, then the joint could be heated to 450° C before it leaked on cooling.

EXPERIMENTAL

Aluminium-wire gaskets were then made in which the ends of the wire were butt-welded together to make an endless loop. The wire was cleaned with fine emery cloth and annealed before use. The experiments to be described were made using a 2 in. diameter aluminium gasket bolted between two stainless steel flanges of 3¾ in. O.D. and ½ in. thick. One of the two flanges was welded to the end of a $\frac{15}{16}$ in. O.D. pipe connected to a vacuum system fitted with a palladium leak detector. The flanges were drilled to take eight ¼ in. B.S.F. high-tensile bolts with 26 threads per in. on a 3⅛ in. pitch circle diameter.

For the first test, each of the eight bolts was tightened under a constant torque of about 9 lb.ft which compressed the 0·036 in. diameter wire to a foil, 0·013 in. thick. At the end of each baking and cooling cycle, the gap between the flanges at four equally spaced points round the circumference was determined, and the average values are given in the table. When the seal was temperature-cycled, it developed a leak after it had been heated to 350° C and cooled. Also, after heating to this temperature, the bolts holding the flanges together had become slack. The bolts were retightened and the seal again tested. The results given in the table show that, in the second test, the flange spacing did not vary over the temperature range 20–460° C. When the vacuum seal was baked at 460° C and allowed to cool, the securing bolts again became slack but the joint did not leak. The flanges

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* Baldock, R., and Sites, J. *Phys. Rev.*, **81**, p. 294 (1951).

Variation in gap between stainless steel flanges at the end of each baking cycle

	Torque per inch of wire (lb.ft/in.)*	*Calculated compression force per inch of wire (lb./in.)*	*Average gap thickness (in.)*								
			Maximum temperature (°C) attained during baking								
			20	150	250	350	400	460	500	550	660
1st test	11·5	22 600 (2 240)†	0·013	0·013	0·0125 (vac. tight)	0·0109 (leaked)	—	—	—	—	—
2nd test (after tightening bolts)	—	—	0·0039	0·0039	0·0039	0·0039	0·0039	0·0039 (vac. tight)	—	—	—
3rd test (new gasket)	17·8	34 900 (4 096)†	0·011 (0·011)	— —	0·0055 —	0·0053 —	0·0048 —	0·0048 —	0·0043 —	(vac. tight)	leake —

* Torque applied using bolts with 26 threads per inch. Compression force calculated from these values. Wire diameter befor compression 0·036 in. All measurements of gap thickness made at 20° C.

† Determined using a hydraulic press.

were then disconnected and it was found that the aluminium gasket had partially welded itself to the two mating surfaces and the flanges required a heavy blow to part them.

A new aluminium wire was fitted between the flanges and the torque on each bolt increased to 14 lb.ft so that the wire was reduced to an average thickness of 0·011 in. The new seal was temperature-cycled, and the results given for the third test in the table show that the gap between the flanges remained almost constant once the temperature had been raised above 400° C. It is of interest to note that, after cooling from 400° C, the bolts securing the flanges became loose but the seal remained vacuum tight up to a temperature of 660° C (i.e. the melting point of aluminium).

A fresh seal was then prepared with a gap of 0·011 in. and tested for leak tightness while being baked in the following sequence: three times at 270° C; once at 350° C and 450° C; three times at 500° C; and once at 550° C. This seal finally leaked at about 660° C. A final test was made in which a new gasket (highly compressed as before) was heated to 500–550° C and then cooled for ten times without leaking. With all of the foregoing seals, the flange bolts became loose at 400–450° C but the joints remained vacuum tight. Also, the aluminium wire gaskets were always partially stuck to the flange surfaces as shown in Fig. 1.

DISCUSSION OF RESULTS

It is believed that the aluminium seal is effective at high temperatures because the combination of compression and heating results in the aluminium adhering to the flange surfaces. When the joint contracts on cooling, the flanges are pulled inwards by the aluminium which is cemented to their surfaces. Thus the seal remains vacuum tight although the securing bolts become loose. It is believed that the "cemented" type of joint is produced as follows: at high temperatures, the plastic flow of the metal is aided both by the weakening of its mechanical strength and by the preferential expansion of the gasket, which increases the compressional force. Undoubtedly the plastic flow of the gasket occurring above 400° C stretches and cracks the oxide skin on its surface and exposes clean metal. The flow of the gasket causes the clean aluminium to rub against the flanges to which it adheres. The flow occurring at normal temperatures is insufficient for cementing to occur so that highly compressed joints which have not been baked part without difficulty. Also, there is a minimum flow (and thus a minimum compression) below which the "cementing" action is insufficient to form a vacuum-tight seal after baking at high temperatures.

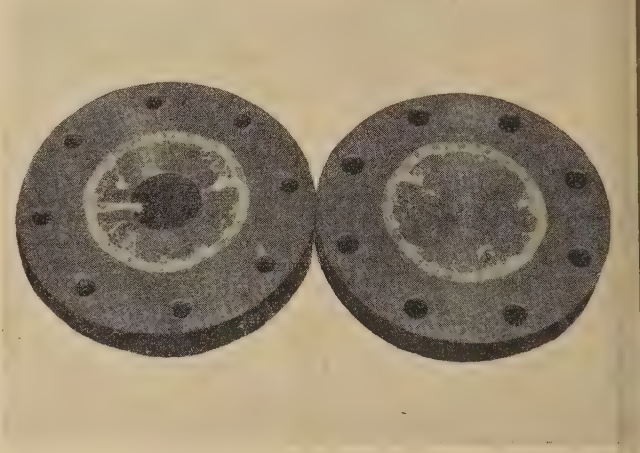

Fig. 1. Appearance of aluminium vacuum seal after baking sequence described in text

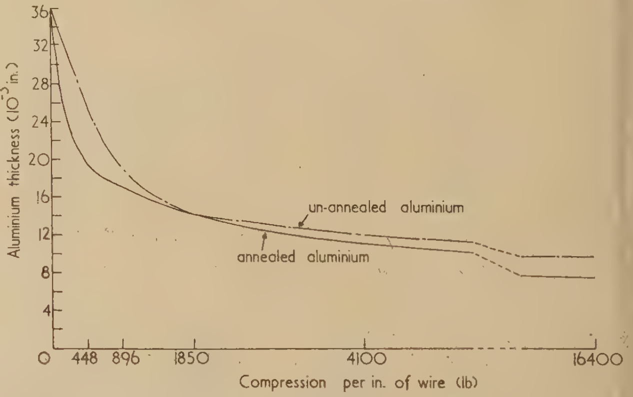

Fig. 2. Variation of thickness of aluminium with compression

It follows therefore that when designing seals of this kind it is important to know the minimum compression forc required, so that the flanges and bolts can be arranged t carry the necessary mechanical load. The compression forc given in the table was calculated from the torque applied to the flange bolts when making the experimental seals, and allowance was not made for mechanical losses in the transmission by the threads. The compression force was therefore determined directly by clamping pieces of aluminium wire ween ground plates in a hydraulic press. The thickness aluminium wire after compression by different amounts is wn in Fig. 2. The results are for annealed and unannealed re. It is shown that a force of 4096 lb./in. of wire is essary to compress annealed wire of 0·036 in. diameter the 0·011 in. thickness required for the cemented seal to m. These results show that the true compression force ing on the wire is much lower than that calculated from torque applied to the bolts as given in the table.

APPLICATIONS

The aluminium-wire seal described here has an advantage er indium even when used in non-bakeable seals because, en clamped between plane flanges with vertical surfaces, retains the profile of the flanges, whereas indium tends to , thus requiring much patience to install. Aluminium-re gaskets have also been used successfully for sealing a mber of different vacuum fittings such as:

(i) mild steel flanges of 14 in. diameter, 1 in. thick, secured by sixteen ½ in. B.S.F. bolts;

(ii) the flanges of metal-to-glass lead-in electrodes;

(iii) a 5 in. diameter glass inspection window compressed on to a mating flange with a mild steel plate (in this application the aluminium wire was crushed to a thickness of 0·010 in. without the glass breaking);

(iv) stainless steel flanges of 6 in. diameter secured by sixteen $\frac{5}{16}$ in. B.S.F. bolts.

In examples (i–iii) it has only been necessary to operate the seals up to 200° C; example (iv) has been operated up to 400° C. Undoubtedly the aluminium seal as earlier demonstrated can be used up to 550° C providing the wire is sufficiently compressed initially.

ACKNOWLEDGEMENTS

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Strobometric method of measuring the phase angles of very low currents

By S. B. GIRVAN, M.Sc., College of Technology, Belfast and D. S. MCILHAGGER, M.Sc., Ph.D., M.I.E.E., Queen's University, Belfast

[*Paper received* 29 *December*, 1958]

A simple device is described by means of which the phase angle of mains-frequency currents may be measured, with respect to the applied voltage, to an accuracy of ± 0·5°. The method was used with currents in the range 0·01 to 10·0 μA but it is not restricted to this range.

hen an alternating potential gradient is applied tangentially an insulator surface, the resultant current has in-phase and adrature components, both of which change with the time application of voltage. In the estimation of insulator rface conductivity, various a.c. bridges may be used to parate conductance and susceptance, and such bridges are tisfactory provided the time rates of change of the parameters are small. When, however, the rate of change of one other parameter is great, and especially when the direction change cannot be predicted (which are the conditions hen the applied voltage gradient over the surface is high), idge methods generally are unsuitable because of the time ken to achieve a balance. The alternative method available to reduce the effective capacitance of the specimen to as low value as possible and to measure the total current and its gle of lead with respect to the applied voltage. (This gle is only appreciable when the surface conductivity is w.) The conductance may then be found from the product the power factor and the admittance.

The device described in this paper enabled total current d phase angle to be measured easily and rapidly. Although e power factor was unity over the greater part of the surface-nductivity range, the constant check on phase angle which e apparatus provided enabled the range of measurable nductivity to be extended by at least one order of magnitude. While the method has been applied specifically to the easurement of the phase angles of currents of the order of 01 to 10·0 μA, it is not restricted to this range.

CONSTRUCTION AND OPERATION

The current of which the phase angle was required was ssed through a non-inductive resistor R_1 (Fig. 1), and the resulting voltage across R_1 was applied to the *Y*-amplifier terminals of a cathode-ray oscilloscope, giving a vertical trace of length proportional to the peak value of the current.

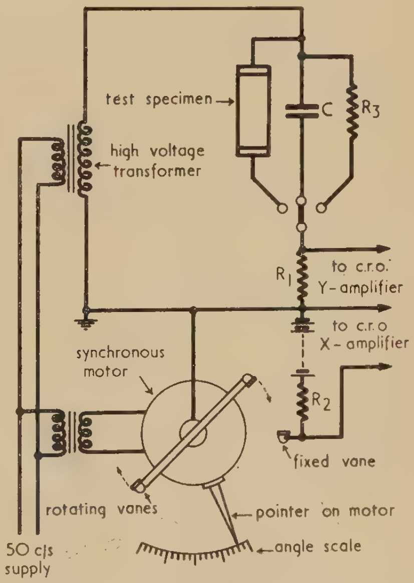

Fig. 1. Electrical circuit of apparatus

Pulses at 180° intervals were injected to the *X*-amplifier, these pulses being produced by a synchronously rotating pair of capacitor vanes as they passed close to a fixed vane. The fixed vane was connected to a direct potential source through a resistor R_2, the rotating vanes being at earth potential, and the charge and discharge currents flowing in the resistor R_2 produced the voltage pulses. The phase positions of the pulses relative to the applied voltage could be varied by rotating the frame of the synchronous driving motor on trunnions, the angular position of the frame being indicated on a protractor.

To obtain a phase reference, the specimen was temporarily replaced by a non-inductive resistor R_3 (or a high-quality, air-spaced capacitor C) and the motor frame was rotated until the two pulses were co-incident at the centre of the vertical trace (Fig. 2). The protractor was then set so that the pointer indicated zero (or 90°). The phase-reference resistor was replaced by the specimen and the motor frame was again rotated until the pulses were co-incident. The electrical angle through which the motor frame was turned from the reference position was indicated on the protractor, and was the phase angle between the specimen current and the applied voltage.

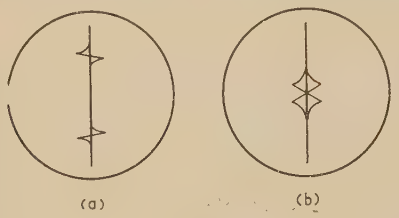

Fig. 2. C.R.O. trace (*a*) with pulses off-centre and (*b*) with pulses centred

In the prototype apparatus, a six-pole synchronous motor was used, and the protractor was scaled in electrical degrees–three electrical degrees being equal to one mechanical degree. With the air-space capacitor C used as a check on the non-inductive resistor R_3, the phase shift between the two currents was found to be 90° ± 0·5°. A further check was provided by the specimen itself: under conditions leading to a high surface conductivity, the phase angle of the current was found to be zero ± 0·5°. In the main, the errors were caused by (*a*) slight changes in torque angle as the motor warmed up and (*b*) "hunting" or phase-swinging. Errors due to motor temperature rise were eliminated almost completely by giving the motor a preparatory warming-up period and by fairly frequent checking against the phase reference. Errors which arise from hunting could be largely overcome by the use of additional torsional damping, but this refinement was deemed unnecessary in the work for which the apparatus was designed.

The d.c. supply to the fixed vane of the pulsing device was obtained by charging a 10 μF capacitor to 500 V, one charge being sufficient for about five hours continuous running. In practice, also, the resistor R_1 was tapped at two suitable intermediate points to provide three current ranges for each decade of the Y-amplifier sensitivity control.

Measurement of low values of internal friction at elevated temperatures

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[*Paper received* 12 *January*, 1959]

Some features are described of an apparatus which measures internal friction of longitudinally resonant specimens at elevated temperatures. The apparatus uses electrostatic drive and frequency-modulation detection, and operates near 100 kc/s, at temperatures up to 1300° C. Limits of operation are discussed, and a comparison made of the observed amplitude-dependent loss at the specimen supports with a simple theory of frictional loss.

The apparatus described here uses the system of electrostatic drive and frequency-modulation detection of the oscillation, developed by Bordoni, and operates from room temperature up to 1300° C. The internal friction of specimens oscillating longitudinally at about 100 kc/s is measured by a decay method.

Previous descriptions have been given of similar types of apparatus, designed to measure either elastic constants or internal friction, and this paper is intended to supplement those accounts, the main purposes being (i) to describe some features of the circuits, (ii) to give details of the furnace and method of mounting the specimen, and (iii) to discuss the operation of the apparatus, with particular reference to mechanical losses at the specimen mounting.

Specimens having very low logarithmic decrement Δ have been measured in the apparatus, and losses at the mounting can occasionally form a major proportion of the total loss. This type of apparatus was chosen for the measurement of low-Δ specimens since it gives minimum contact with the specimen. Composite oscillator systems using cemented-on drive transducers have the disadvantage of producing thermal stresses at the junction, which can introduce extra damping(1) when used over a wide temperature range. Fig. 1 gives a general view of the apparatus.

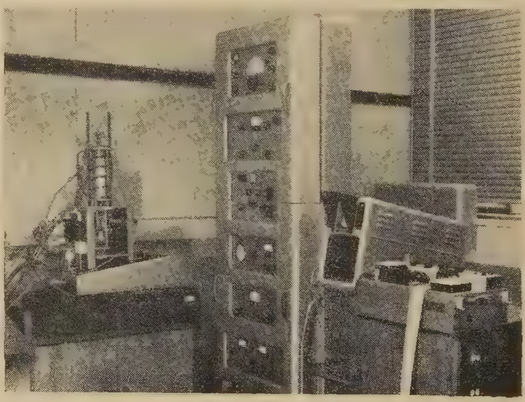

Fig. 1. General view of apparatus

SYSTEM OF OPERATION

Discussion of the merits of the system and full details of the circuits will not be given here, as the subject has been ered elsewhere.(2,3,4) Bordoni(2) has demonstrated that illation amplitudes of 0·1 Å at 10–50 kc/s can be measured. borations of the electronic circuits have been described Pursey and Pyatt(3) and by Vernon,(4) who have applied apparatus to accurate measurement of elastic constants; d the upper frequency limit has been extended by Bordoni d Nuovo,(5) who showed that oscillations of up to 5 Mc/s n be excited electrostatically if a mica dielectric is inserted the drive gap. This latter method is not suitable for urate internal-friction measurements.

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A block diagram of the system is shown in Fig. 2. A nducting plate, the drive plate, is spaced about 0·2 mm m the end face of the specimen, and the gap between the ate and the specimen is used both for electrostatic drive d for measurement of specimen vibration amplitude, the p capacity variations modulating a 30 Mc/s oscillator. e detector oscillator resonant circuit is closed by a 200 pF pacitor, which offers a low impedance to the 30 Mc/s signal thout short-circuiting the specimen drive. After detection the 30 Mc/s signal modulation in an f.m. receiver, which es a simple Foster–Seeley discriminator circuit, the resulting nal is amplified and fed to a logarithmic recorder, type 04 (by Bruel and Kjaer). Thus, if the specimen is first set o oscillation and then the drive switched off, a straight e is obtained if the logarithmic decrement Δ is constant. e slope of this line, together with the frequency of oscil-ion, gives Δ. Alternatively, departures from linearity give immediate indication of dependence of Δ on oscillation nplitude.

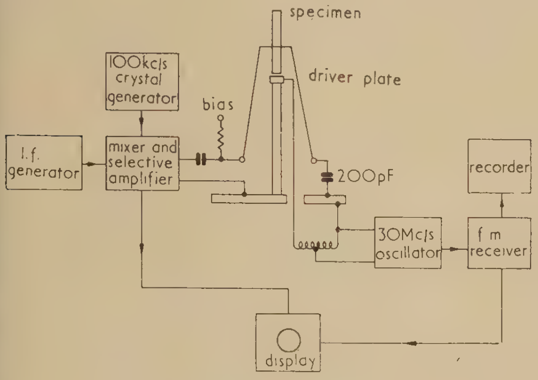

Fig. 2. Block diagram of system

In addition to the drive signal, a static bias is applied to e gap. This obviates frequency doubling of the drive, and creases the available driving force, for a given applied ternating voltage.

Decrement values as low as 10^{-7} may be measured in the pparatus, and hence a very high stability is demanded from e drive generator, since with this Δ, at 100 kc/s, the response rve width is only 3×10^{-3} c/s. A crystal-controlled cillator, giving an output of fixed frequency near the ecimen resonance, is used as a basic generator, and the itput is modulated by a stable oscillator of lower frequency, e appropriate side-band of the modulated carrier being lected by a narrow-band amplifier. Further amplification effected in a broader-band amplifier. The resulting sinu-idal drive signal frequency can thus be varied sufficiently follow variations in specimen frequency with temperature. or specimens having low Δ, the behaviour while setting up e oscillation is complicated, and it is necessary to display e elliptical trace of drive signal against f.m. receiver output n an oscilloscope to be able to locate the resonant frequency sufficiently accurately. This behaviour also makes the response curve method of determining Δ quite impracticable.

The f.m. receiver and subsequent 100 kc/s amplifier are designed to give undistorted amplification, and all power supplies are stabilized, so that a faithful record of the decay curve is obtained. The amplifier has a narrow bandwidth to reduce extraneous noise. The discriminator characteristic, on the other hand, is designed to be linear over a frequency range of at least twice the specimen resonant frequency so that the sensitivity is the same at the modulating frequency as for static frequency shifts, enabling static calibration of the gap sensitivity to be carried out.

SPECIMEN FURNACE AND SUPPORT

Ideally, the furnace should contain a minimum of heated material. Thus (i) contamination of the specimen by evaporation of impurities will be minimized and (ii) cooling times will be short, so that quenching experiments can be carried out *in situ*. For these reasons, a molybdenum-tube furnace is used. Fig. 3 shows a cross-section of the arrangement.

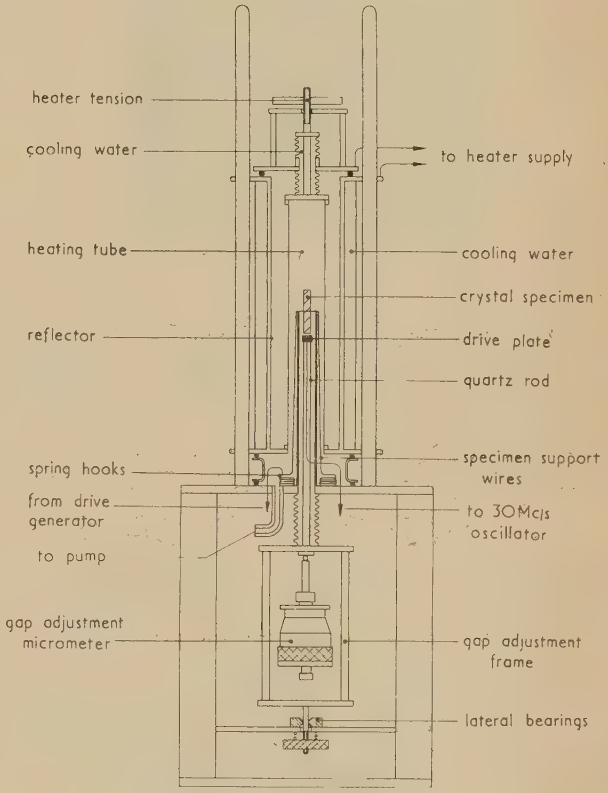

Fig. 3. Section of furnace and specimen mounting

Thermal insulation is provided by polishing the interior of the water-cooled aluminium vacuum jacket, a radiation shield (not shown) between the heating element and the reflector serving to improve thermal insulation, and also to prevent contamination of the reflector, which would otherwise drop rapidly in efficiency as soon as a thin film became deposited. The heater tube is 20 cm long, formed from 0·035 mm molybdenum foil. The furnace space is evacuated, to eliminate both air damping and, at higher temperatures, oxidation. Electrical insulation of the "live" end of the heater tube is effected by the O-ring which also acts as a vacuum seal for the furnace end plate.

With a furnace input of 5·2 V, 150 A, the specimen attains a temperature of 1350° C. The rate of cooling at higher temperatures is rapid, the temperature falling from 1100° C to 600° C in 2 min. Since cooling is determined almost entirely by radiation, it is considerably slower at lower temperatures.

The specimen is supported by two 0·03 mm tungsten wires stretched across the end of a 1·3 cm diameter silica tube, as shown in Fig. 4. The supporting force is purely frictional, no grooves being cut in the specimen, and the wires are tensioned at their lower end by small adjustable spring hooks. The drive plate is made of molybdenum, and is held in position at the top of the central silica rod by molybdenum wires which are secured at the lower end of the rod. Adjustment of the drive gap can be carried out quite effectively by eye as the mounting wires are tightened.

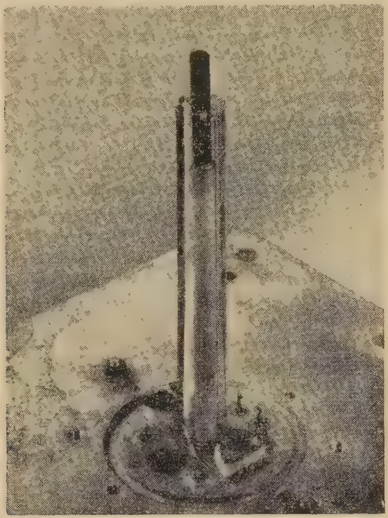

Fig. 4. Specimen in position. The mounting wires are emphasized for clarity

PERFORMANCE

With this apparatus, specimen vibration amplitudes of down to 0·5 Å can be measured. The maximum measurable Δ is determined by the rather limited drive power provided by the system, since a maximum is placed on the drive voltage by spark-over of the gap; and also by the limited response speed of the recorder. At low temperatures this maximum Δ is about 10^{-3}. Difficulties arise at temperatures above 1100° C because direct modulation of the 30 Mc/s oscillator by the drive signal occurs, probably by a thermionic emission process, and the modulation masks the resonance of the specimen. For this reason Δ of greater than 10^{-4} cannot be measured at these higher temperatures in the present apparatus. The general noise level also increases, and the minimum measurable amplitude becomes greater than 0·5 Å.

The lowest measurable Δ is determined by the external losses. Atmospheric (of the order of 10^{-5} mm of mercury) radiation and losses into the drive system can be shown to give a decrement of less than 10^{-9}, and the major losses are along the support wires. There are two forms of loss, giving rise to (i) amplitude dependent Δ (friction loss), and (ii) amplitude independent Δ (transmission loss); and both forms will be discussed in the next section. Measurements can be satisfactorily carried out on silicon specimens up to 1300° C, although reaction with the tungsten wire takes place above 1250° C. If, with different specimen materials, wires oth than tungsten have to be used, larger diameters would needed to give sufficient strength, leading to larger mechani loss through the wire.

If an annealing process is being studied it is often necessa to plot the curve of Δ against temperature rapidly, and the is not time for the apparatus to come to thermal equilibriu before each measurement. It has therefore been found co venient to use the temperature/resonant-frequency characte istic of the specimen for rapid measurement of the temper ture. The method is only suitable for specimens having stable characteristic, but has the advantage that, should a temperature gradient exist along the specimen, the resona frequency will be mainly determined by the more high stressed region of the specimen, which contributes pr dominantly to Δ.

MOUNTING LOSS

If no slip occurs between the specimen and the mounti wires, the power transmitted along the wires is proportion to the square of the specimen vibration amplitude, and hen Δ from this cause is amplitude-independent. If the wir are accurately located in a nodal plane, the motion, dete mined by Poisson's ratio, is entirely in this plane. The ca culations of Bordoni,(2) which apply to very long suppo wires, show that the power is carried mainly by the long tudinal wave, and that the contribution Δ_R to Δ produce by tungsten wires 0·03 mm in diameter supporting a 5 m square silicon specimen vibrating at 100 kc/s is approximate 4×10^{-6}. This is a larger loss than actually observed in th apparatus, the minimum Δ being 7×10^{-8}, and it must b assumed that resonance effects in shorter wires can reduc the loss. A minimum value would be expected when th wires are a quarter-wavelength long, i.e. about 1 cm. Henc the lengths used, about 5 mm, are rather short; but the us of the full quarter-wave would increase the size of th apparatus unnecessarily.

A more complex effect appears if slip takes place betwee the support wires and the specimen. A simplified analys can be carried out if it is assumed that there is a maximum constant-valued, frictional force between the wire and on edge of the specimen. The calculation in the Appendi shows the resulting loss as a function of strain amplitude a the centre of the specimen, on the assumption that only on wire slips at a time. The maximum Δ_F from this cause i independent of the value of frictional force *F*, and for th tungsten wires and silicon specimen mentioned previousl gives Δ_{max} to be approximately 4×10^{-6}.

In practice, amplitude dependent Δ occurs only sporadic ally, presumably when the frictional force happens to becom of the right order of magnitude. That this dependence is due to the mounting wires is evident from its sensitivity to sligh shifts in mounting wire position produced by tapping. Two kinds of dependence are seen, and typical curves are plotted in Fig. 5, where Δ is given as a function of the logarithm of the strain amplitude. Curve (*a*) approximates to the type of variation just discussed, and a theoretical curve of the form derived in the Appendix is plotted on the same scale. Curve (*b*) would be obtained from a contact having a frictional force steadily increasing with increasing vibration amplitude, having no limiting value of friction within the range measured.

The maximum Δ of the theoretical curve of Fig. 5(*a*) is about three times the value previously derived. Such a disparity indicates that the actual lateral motion of the specimen edge is about $\sqrt{3}$ times that given by the Poisson's ratio. This extra displacement could be produced by slight artures of the specimen shape from a true parallelepiped, by heterogeneity of the elastic properties, introducing a ural component of oscillation, and it is indeed observed t non-uniform poly-crystalline specimens frequently show ge amplitude dependence of Δ. The strain amplitude $\times 10^{-7}$ at which maximum Δ occurs indicates that in s case the frictional force is of the order of 1 dyn, that

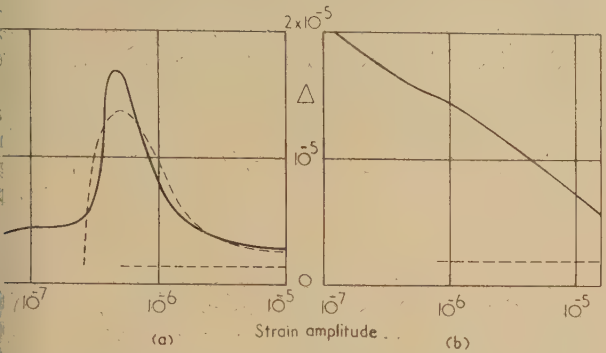

Fig. 5. Typical curves showing amplitude dependence of Δ. The dashed curve in (*a*) is from the theory given in the Appendix

the coefficient of friction is in the 10^{-3}–10^{-4} region, the rmal force exerted by the wires being of the order of eral grams. It is not unreasonable to assume that such all coefficients of friction can apply to motion in the rizontal direction, while the vertical friction is sufficiently ge to support the specimen. In platinum, a relatively soft terial, it has been shown$^{(6)}$ that the static coefficient of ction drops with decreasing displacement to values as low 5×10^{-2} for displacements of the order of 100 times se encountered here.

It is evident that agreement between the theoretical and served curve is only moderately good, but this would be pected from the simple nature of the theory. More detailed ormation on the frictional force F could be obtained by nsidering the variation of F with displacement during slip. ually the force is sufficiently high to prevent slip and does t affect Δ measurements, but attempts to construct a unting which does not occasionally give frictional losses ve not been successful. The occurrence of mounting loss however, not sufficiently obtrusive to interfere seriously th the accurate measurement of low Δ values.

APPENDIX

Loss due to mounting wire slip. The support wires are etched across the specimen face, of width d_1, and are chored at distance d_2 from the specimen edges. It is sumed that slip occurs only at point A (Fig. 6). The curve ows the component of the specimen edge displacement ong the wire ζ and the displacement of the wire at the ge ζ_1. The slip distance is z.

In the first quarter cycle of oscillation,

$$\zeta_1 = \zeta_0 \sin \omega t + \frac{z}{2}$$

fore slip, and

$$F = \zeta_1 \frac{M}{d_2} + \left(\zeta_1 + \zeta_0 \sin \omega t\right)\frac{M}{d_1} \qquad (1)$$

ring slip, where ζ_0 is the amplitude of lateral expansion of specimen, M the elastic modulus of the wire, and F the ctional force.

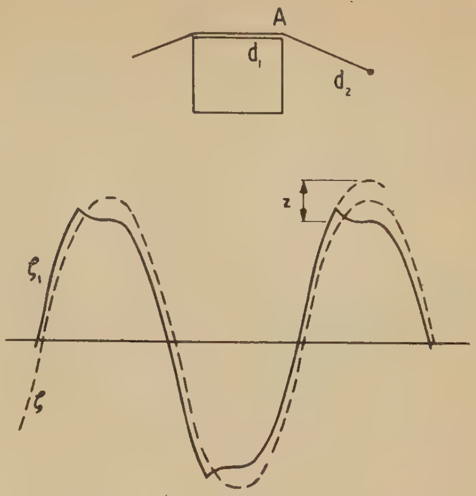

Fig. 6. Motion of specimen edge and contacting support wire

Because

$$\zeta_{1(max)} = \zeta_0 - \frac{z}{2}$$

then, from equation (1),

$$z = \frac{\zeta_0 M\left(\frac{1}{d_2} + \frac{2}{d_1}\right) - F}{\frac{M}{2}\left(\frac{1}{d_2} + \frac{1}{d_1}\right)}.$$

Now

$$\Delta_F = \frac{\delta W}{2W} = \frac{2Fz}{2 \,.\, \frac{1}{2} m\omega^2 \xi_0^2}$$

W being the mechanical energy, ξ_0 the oscillation amplitude of the end of the specimen, and m the half-mass. In a uniform bar of length l, having a Poisson's ratio ν,

$$\zeta_0 = \frac{\nu d_1}{2}\varepsilon \quad \text{and} \quad \xi_0 = \frac{l}{\pi}\varepsilon,$$

where ε is the strain amplitude at the centre of the specimen. Therefore

$$\Delta_F = \frac{4F\pi^2}{m\omega^2 l^2} \cdot \frac{\left(\varepsilon - \frac{F}{M} \cdot \frac{1}{\nu a}\right)}{\varepsilon^2} \cdot \frac{\nu a d_1}{b}$$

where

$$a = \frac{d_1 + d_2}{d_2}, \quad b = \frac{d_1 + 2d_2}{2d_2}$$

The maximum value of Δ_F is thus

$$\Delta_M = \frac{\pi^2 a^2 \nu^2}{b} \cdot \frac{d_1 M}{m\omega^2 l^2}$$

at a strain

$$\varepsilon = \frac{2F}{M} \cdot \frac{1}{\nu a}.$$

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Laboratory and workshop notes

Integrator for a self-balancing potentiometer

By J. W. McHugo, B.Sc., A.R.C.S., A.Inst.P.,* Fuel Research Station, London, S.E.10

[*Note first received* 18 *September*, 1958, *and in final form* 21 *January*, 1959]

The device described here was developed at the Fuel Research Station as part of a system for mechanizing the measurement of radiation output from solid-fuel-fired heating appliances, using the Moll thermopile arc radiometer.† The requirement was to measure and add successive output readings from the thermopiles (in the range up to 50 mV), there being five readings taken at intervals of about ten seconds in each arc traverse, and a traverse every ten minutes throughout a six-hour test.

It was decided to use a high-speed self-balancing potentiometer in place of the galvanometer employed with a hand-operated arc. A chart recorder was not necessary, but as a potentiometer of this type was available it was modified by removing the chart assembly; this was a multi-line instrument, but the line-changing mechanism could be switched off so that one input line could be used for continuous indication.

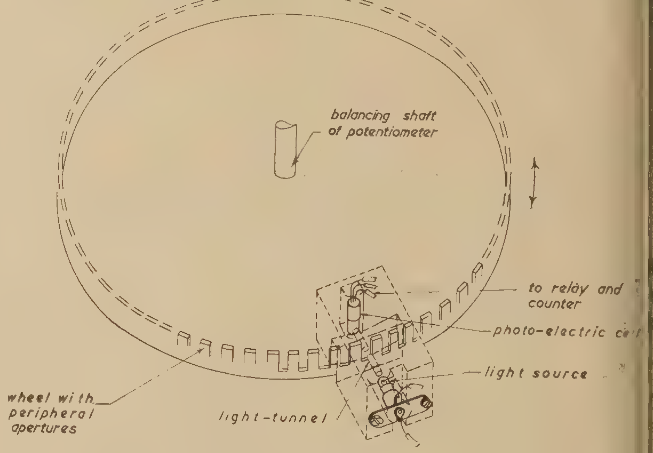
The principle of the integrator is as follows. The mechanical drive in the self-balancing mechanism is connected through a clutch to a counter. The potentiometer is short-circuited between each reading, and the transmission to the counter is made while it is driving up into balance but broken while it is driving down to zero. In this way the counter registers and adds shaft rotations proportional to each reading. The necessity of returning to zero is no disadvantage because it occurs while the radiometer arc is moving from one measuring position to the next.

An electrically-operated mechanical clutch for the counter transmission was at first envisaged, but the suggestion was made that a photocell and chopper-wheel system operating an impulse counter would be simpler to construct and fit in the potentiometer. By switching the illuminating lamp for the photocell on and off automatically, the photocell, and hence the counter, can be rendered operative only during the outward movement of the potentiometer pointer; it is, of course, necessary to ensure that the potentiometer does not overshoot on driving into balance, as this would cause a spurious count.

The arrangement adopted is shown in the figure. An aluminium alloy disk with a flange was fitted on the balancing shaft; the flange was cut into sixty-six teeth, and was arranged to interrupt the light beam between a 6 V L.E.S. bulb and a Mullard type OCP71 phototransistor, both mounted in a Tufnol block. The output from the phototransistor was not sufficient to operate a high-speed counter directly; it was therefore fed through a high-speed relay to the counter, a SODECO model capable of registering twenty-five impulses per second.

Of the sixty-six teeth on the integrator disk, fifty cross the light beam for a full-scale movement; as this takes about two seconds, the full speed-rating of the counter is required. The 2% (of full scale) discrimination provided by fifty teeth is adequate for this application, in which a normal six-hour test would require the summation of 180 readings.

To operate the integrator, switches are required to connect or short-circuit the potentiometer input and to switch the photocell illumination on or off. These functions are performed by relays in the main timer, which controls the movement of the mechanized radiometer arc. The arrival of the arc at a measuring position initiates the following sequence of operations. The photocell illumination is switched on and then, one second later, the short circuit is removed and the potentiometer is connected to the thermopiles. Counting takes place while the potentiometer drives into balance; five seconds are allowed for this stage to ensure that the thermopiles have attained stability. Next, the photocell is switched off and, one second later, the potentiometer is short-circuited and drives to zero while the arc is moving to its next position. The two one-second delays ensure that the photocell is correctly set before the potentiometer operates. A complete 180° traverse by the arc takes sixty-five to seventy seconds.


balancing shaft of potentiometer
to relay and counter
photo-electric ce
light source
wheel with peripheral apertures
light-tunnel

Arrangement of lamp and photocell on toothed wheel

This integrating device might have application to other uses of high-speed multi-line potentiometers. Because the lamp and photocell arrangement is not sensitive to the direction in which the balancing shaft rotates, it could be left operative all the time and allowed to produce impulses for the outward and return rotations. The technique described, however, shows the method by which the device was developed; it has the merit that it is applicable to other types of clutch for cases where space, etc., preclude the use of a lamp and photocell.

The type of integrator which is available for circular-chart recorders (as used for flow-rate measurement) is not suitable for multi-line recorders, but an integrator for a slower speed multi-line self-balancing bridge has been described by Pratt and others‡; this made use of a single hunting uniselector and impulse counter for each of the lines. Because of the wiring required for the uniselector, it is possible that the integrator described here is simpler to instal; it is also probably more suitable for higher speed recorders. If it is l with a multi-line instrument, the output from the photo- would be switched to different counters by the line- ging mechanism; it should also be possible to arrange for mechanism to control the short circuit on the potentio- er input and the operation of the clutch. The components ne integrator were designed so that it is possible to replace chart assembly without interfering with the integrator ration.

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* Now at Royal Aircraft Establishment, Farnborough, Hampshire.

† Fox, L. L., Heselden, A. J. M., and Whittaker, D. *J. Inst. Fuel*, **30**, p. 492 (1957).

‡ Pratt, A. W., Collins, B. G., Lacy, R. E., and Spink, E. W. *Proc. Instn Elect. Engrs* (71) **98**, p. 474 (1951).

he work described in this paper formed part of the gramme of the Fuel Research Board of the Department Scientific and Industrial Research and is published by nission of Mr. S. H. Clarke, then Director of Fuel earch. The illustration is Crown copyright and is pub- ed by permission of the Controller of H.M. Stationery ce.

Stable radio-frequency lamp supply

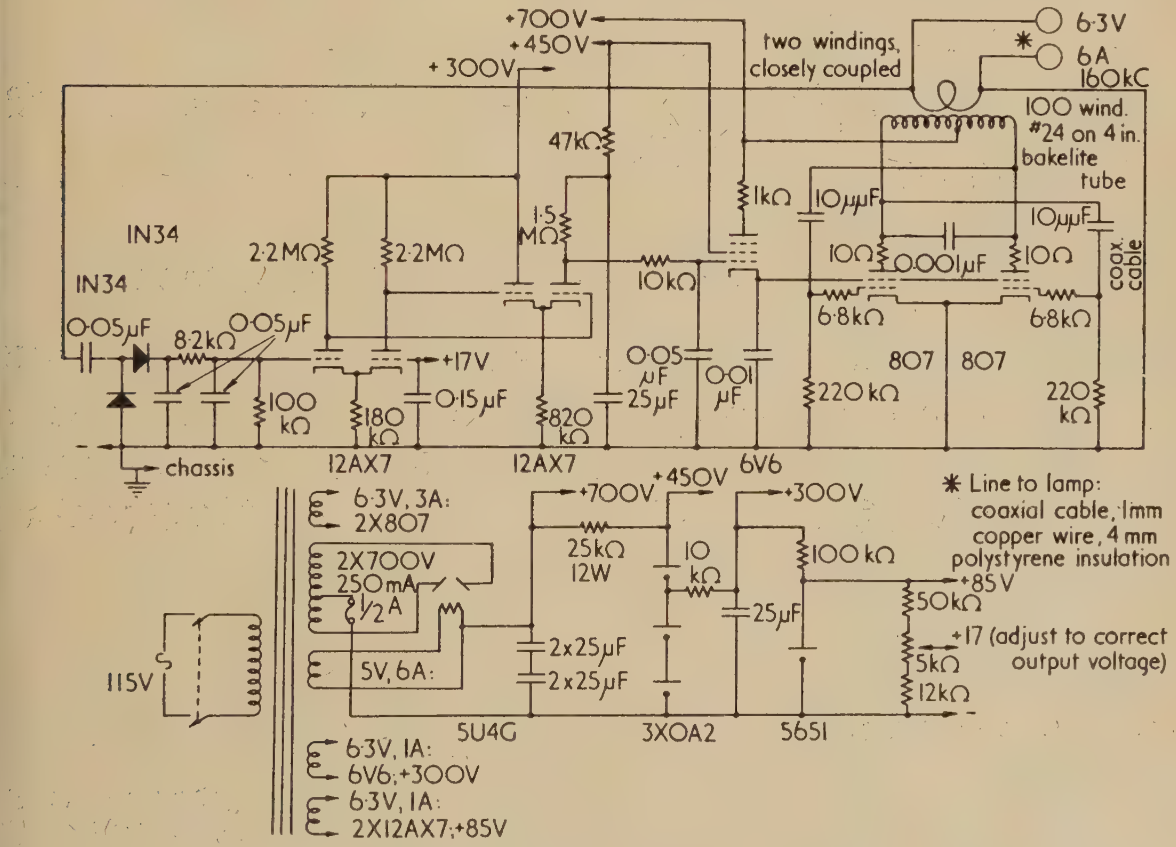
y A. S. Brill* and H. den Hartog†, E. R. Johnson
oundation for Medical Physics University of Pennsyl-
vania, Philadelphia 4, Pennsylvania

[*Note received 5 November*, 1958]

regulated lamp supply of the figure is used in a system measuring the angular deflexions of the suspension of a kine balance type magnetic susceptometer.(1) The environment of the balance must be free from masses of iron and d.c. magnetic fields, which suggested a radio-frequency supply. A required voltage stabilization of 1:1000 for 10% line voltage fluctuation is met. Another useful application would be in spectrophotometry where tungsten incandescent lamps are usually run on regulated d.c. and hence tend to exhibit excessive noise due to migration of tungsten atoms across the filament surface.(2, 3, 4) When fluctuations must be kept quite low, a 60 c/s supply is also unacceptable because of flicker.

The power is supplied by two 807 valves connected as a push-pull Hartley oscillator. The inductance of the tank circuit is part of a transformer coupling to the output. After rectification and doubling, the output voltage is compared to a reference voltage with a two-stage difference amplifier. The amplified difference voltage is applied to the grid of a cathode-follower which has for the cathode load the 807 screen circuits.

The authors are pleased to thank Dr. L. H. van der Tweel of the University of Amsterdam for the circuit shown in the figure which includes several improvements on our original circuit.


+700V
+450V
+300V
two windings, closely coupled
6·3V
✱
6A
160kC
100 wind. #24 on 4 in. bakelite tube
47kΩ
1kΩ
10μμF
10μμF
1·5 MΩ
IN34
IN34
2·2MΩ
2·2MΩ
100Ω
0·001μF
100Ω
coax cable
10kΩ
6·8kΩ
6·8kΩ
0·05μF
8·2kΩ
0·05μF
+17V
0·05 μF
0·01 μF
807
807
100 kΩ
180 kΩ
0·15μF
820 kΩ
25μF
220 kΩ
220 kΩ
chassis
12AX7
12AX7
6V6
+700V
+450V
+300V
6·3V, 3A: 2X807
2X700V 250mA
½A
5V, 6A:
25kΩ 12W
10 kΩ
100kΩ
25μF
2x25μF
2x25μF
+85V
50kΩ
+17 (adjust to correct output voltage)
5kΩ
12kΩ
✱ Line to lamp: coaxial cable, 1mm copper wire, 4 mm polystyrene insulation
115V
5U4G
3XOA2
5651
6·3V, 1A: 6V6;+300V
6·3V, 1A: 2X12AX7;+85V

Schematic circuit of regulated lamp supply

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Now at The Clarendon Laboratory, Parks Road, Oxford, gland.

Now at Department of Physics, University of Amsterdam, sterdam, The Netherlands.

Attachment to the Philips 11·46 cm diameter X-ray powder camera

By A. Barclay, F. G. Buttler and H. F. W. Taylor,
Chemistry Dept., University of Aberdeen

[*Note received* 3 *October* 1958]

This device, to be attached to the Philips 11·46 cm diameter X-ray powder camera, was made so that 6 cm diameter powder photographs could be obtained for direct comparison with single-crystal photographs taken using a Unicam type S.25 X-ray goniometer of the same diameter, thus leaving the latter instrument free for single-crystal work. No modifications to the Philips camera were needed, and the attachment is easily fitted or removed.

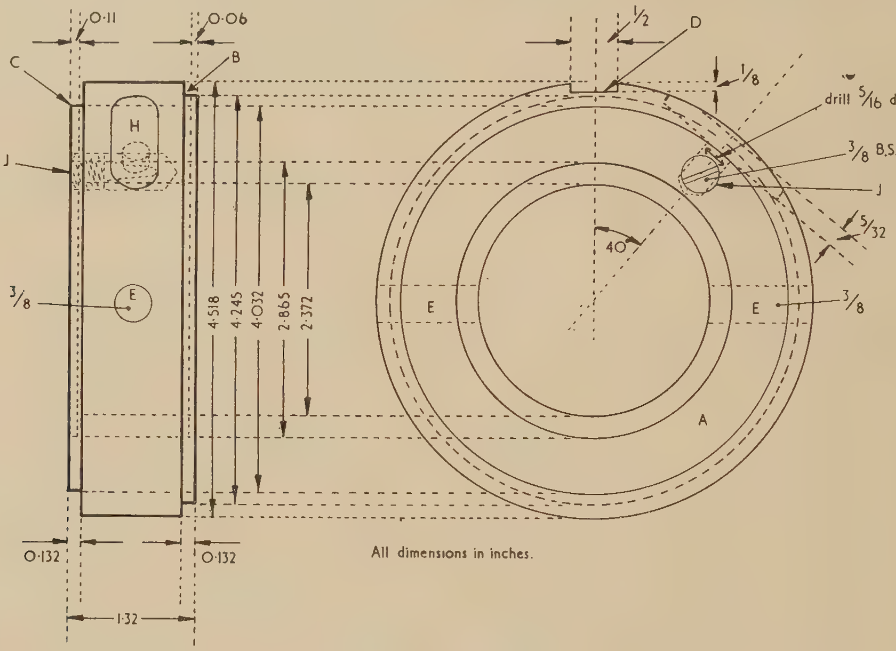

0·11
0·06
C
B
J
H
3/8
E
4·518
4·245
4·032
2·865
2·372
0·132
0·132
1·32
1/2
D
1/8
drill 5/16 dia
3/8 B.S.F.
J
5/32
40°
E
E
3/8
A
All dimensions in inches.

Fig. 1. Scale drawing of the attachment

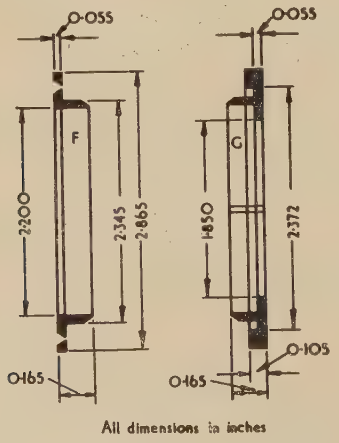

0·055
0·055
F
G
2·200
2·345
2·865
1·850
2·372
0·105
0·165
0·165
All dimensions in inches

Fig. 2. Film rings (*F* and *G*). (Not drawn to scale)

The attachment (Fig. 1) consists of a Duralumin ring *A*, with an outside diameter of 11·46 cm to fit inside the powder camera, and an internal diameter of 6 cm + 0·01 in. which allows for the thickness of the film. Recesses were turned o the outside to accommodate projections in the camera bas at (*B*), and in the lid (at *C*). A groove *D* was cut into the to of the attachment to clear the film-locking device of the powde camera, and holes *E* were drilled through the attachment fo the collimator and backstop. The film is held in place by tw rings, the bottom one *F* fixed, and the top one *G* spring loaded to clip the film in position, as shown in Fig. 2 Recesses were turned on the inside of the Duralumin ring t accommodate these.

The attachment is held in position by a locking device, *F* and *J*, shown in Fig. 1 and in an exploded form in Fig. 3. A piece of brass *H*, with a radius of curvature of 5·73 cm ove its outside edges, but flattened at the top, and leaving a angled leg, was let into the outside edge of the attachment This was pressed against the inside of the 11·46 cm diamete camera by means of the tapered screw *J*. This locked th attachment firmly in position without causing any damage t the camera. The collimator and backstop were pushed int position through their usual holes in the camera and throug the holes *E* in the attachment. The specimen was mounte in the usual way, and a nickel foil filter was either placed i contact with the film, or supported on the collimator an backstop about half-way between the specimen and the film

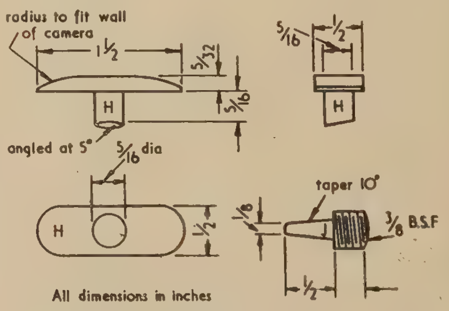

radius to fit wall of camera
1½
5/32
5/16
H
angled at 5°
5/16 dia
5/16
½
H
H
½
taper 10°
1/8
J
3/8 BSF
½
All dimensions in inches

Fig. 3. Locking device. (*H* and *J*)

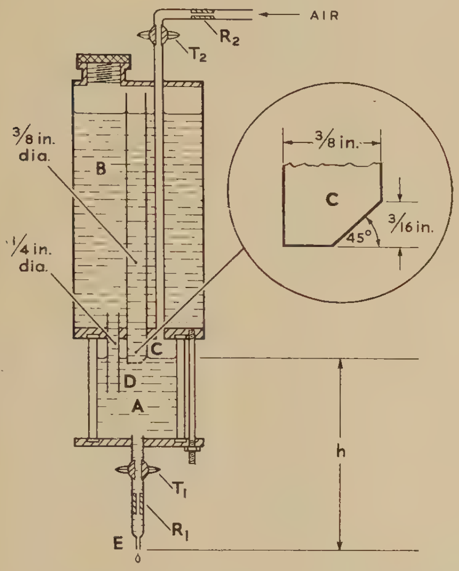
Constant-head aspirator

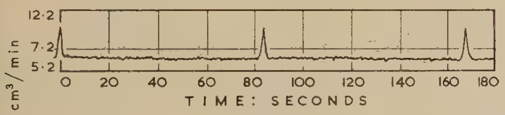
y S. R. Howarth, Safety in Mines Research Establishment, Sheffield

[*Note first received* 27 *October, and in final form* 25 *November*, 1958]

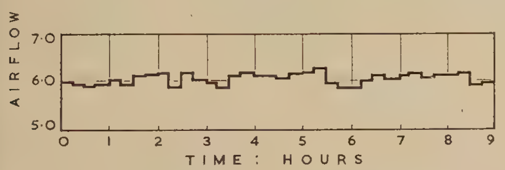
sampling airborne dust, and for other purposes, it is often ired to draw air through an instrument at low and constant es of flow. The apparatus described aspires at flow rates m 1 to 10 cm^3/min. It is simple, portable and robust.

he principle of the aspirator is shown in the figure. ps T_1 and T_2 are opened and water drips slowly out of the





Variation of flow rate over two operating cycles



Long period variation of flow rate

Construction and performance of constant-head water aspirator

E, drawing air into the lower chamber A until the water vel falls below the bottom of the tube C. The meniscus en breaks and air escapes from the lower chamber A to e top of the reservoir B *via* the tube C. At the same time e lower chamber is replenished *via* tube D with water from e reservoir, and the operating cycle begins again.

The dimensions of the apparatus are by no means critical cept for the air-escape tube C: the 45° cut-away at the ttom helps the meniscus to break and re-form reproducibly. he extension of the upper portion of the tube above the ater level in the reservoir helps to limit the periodic surge used by the rapid buoyant rise of bubbles in, and ejection water from the top of, tube C. If the diameter of C is made too small air tends to flow backwards through R_2 during the surge. Although the flow-rate could be regulated entirely by the water resistance R_1 it is necessary to provide some air resistance R_2 so as further to damp the surge. The resistance of R_1 must not be too low, or air may be sucked up through the water jet E when chamber A refills. The flow-rate may be adjusted continuously over a fairly wide range by varying the pressure head h: it is convenient to put the water resistance R_1 on the end of a flexible tube for this purpose. The resistances themselves may be hypodermic or glass capillary tube or needle valves.

The flow-rate and cyclic operation of the aspirator is scarcely affected by small departures from the vertical of a few degrees. Any increase of pressure drop at the air inlet, due, for example, to the collection of airborne dust on a filter paper,$^{(1)}$ must, of course, be small compared with the driving pressure head h.

To prevent the formation of air bubbles, degassed tap water should be used. This may be prepared by enclosing the water in a suitable vessel and maintaining a partial vacuum (about 10 cm of mercury is sufficient) above the water surface for a few hours. With an aspirator whose metal parts were made of brass, maintenance was confined to an occasional wash out of the interior with hot water and cleaning of the resistances. No difficulties were experienced with corrosion provided distilled water was not used. The lower chamber A was of glass and whilst this is a great convenience it is not essential. The volume of the reservoir B may be adjusted to suit the circumstances, but about 500 cm^3 to 1 litre should be adequate for most purposes.

Continuous observations of the flow-rate have been made with a flowmeter consisting of a light, 1·5 mm diameter ball in a vertical glass tube whose bore cross-section increases with height.

The trace of the ball photographed on moving film shows that the flow-rate within an 85-second cycle is constant to within ±5% except for the 2-second surge, but this adds only $1\frac{1}{2}\%$ to the average flow-rate. The record of average flow-rate in successive 15-minute periods, obtained by timing the collection of water in a measuring cylinder, remains constant to within ±4% over a period of 9 hours. The aspirator was stopped and reservoir B was refilled every 75 min, but otherwise no adjustments were made.

With the resistance R_2 rigidly attached to the body of the aspirator and taps T_1 and T_2 closed, the aspirator may be carried about full of water and even inverted before use without affecting its performance.

This note is published by permission of the Ministry of Power.

REFERENCE

(1) Dawes, J. G., Howarth, S. R., and Slack, A. *Safety in Mines Research Establishment Research Report* No. 87 (Sheffield: Safety in Mines Research Establishment, 1954).

Opener for radioisotope bottles

By G. R. Taylor, M.Sc., A.Inst.P., and H. A. Malcolm
Physics Department, Northern Ireland Radiotherapy Centre, Purdysburn, Belfast

[*Note received* 20 *November*, 1958]

Radioisotopes are supplied to this department by the Radiochemical Centre as solutions in standard glass bottles, sealed by a re-entrant rubber bung and aluminium cap. Because of a tendency of a fraction of the bottle contents to collect in the re-entrant rubber bung, difficulties arise in association with the extraction of the solution from the bottles. Removal of the bung using forceps frequently leads to "spraying" of some of the radioactive solution. Techniques involving a syringe or double needle are considered to be time consuming and lead to contaminated apparatus and consequently are not employed at this centre.

Recent descriptions of two bottle openers$^{(1,2)}$ have encouraged us to record details of an opener designed and constructed in this department. The mode of operation and constructional details can be seen from Fig. 1. The body and working parts of the instrument are of brass, the circular section arms of silver steel and the knife edge jaws of stainless steel. With the exception of the jaws the whole assembly is satin chromium plated. The stainless steel jaws are easily removable for de-contamination or replacement when necessary.

An opener for radioisotope bottles should satisfy two possible requirements, namely removal of the bung and metal cap either together or separately. The first is easily accomplished with the bottle held in a lead pot, the opener being long enough for the hand to be out of the direct beam of radiation from the isotope. Firm grasping of the metal cap and rubber bung combined with a slight levering movement ensures slow controlled removal of both. The essential feature of the operation being that pressure exerted by the jaws between the glass and lip of the rubber bung causes the lower crimped edge of the metal cap to move away from the glass.

Separate removal of the cap and bung is possible if the opener is used in conjunction with the simple claw tool shown in Fig. 2. The metal cap is removed with the claw tool and the stainless steel jaws of the opener are gently engaged under the lip of the rubber seal which can then be safely removed. When the claw tool is being used, the rubber bung very occasionally tends to lift with the metal cap. The first technique is then employed and the bung later extracted from the cap.

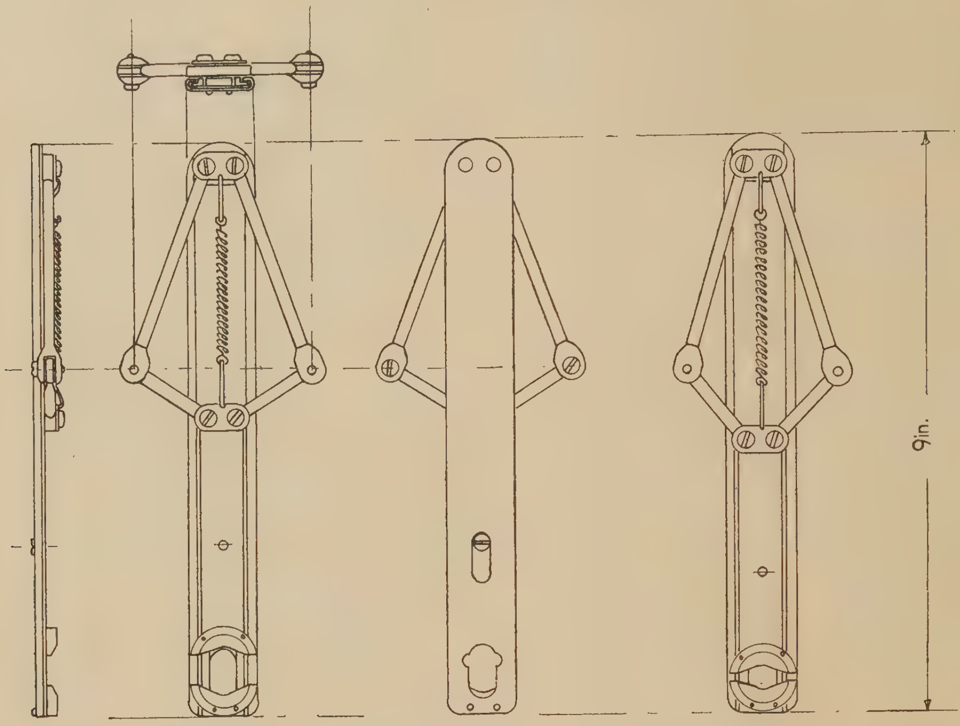


Fig. 1. Construction and mode of operation of the opener

Both operations are carried out in this department from behind a lead wall and as the times involved are approximately 3 and 7 s respectively the radiation hazard in minimal. The opener has proved safe and speedy to use, it is simple to construct, and is easily de-contaminated when necessary.

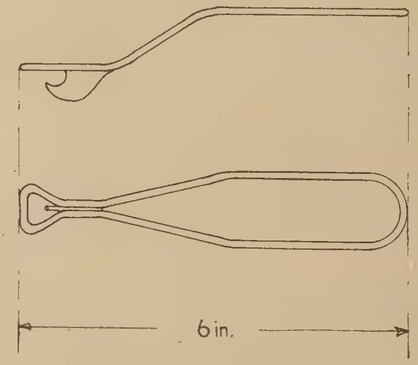


Fig. 2. Elevation and plan of the "claw" tool

REFERENCES

(1) Clayton, C. G., Hepplewhite, J. and Lucas, F. A. *Brit. J. Radiol.*, **30**, p. 614 (1957).

(2) Hoather, W. H. *Brit. J. Radiol.*, **31**, p. 515 (1958).

New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

gh speed recording oscilloscope. Oliver Pell Control Ltd., Cambridge Row, Burrage Road, London, S.E.18.

e Redcliffe type 1239A oscilloscope is intended for the ual and photographic observation of transients with a rise ıe of the order of 4 mμs. It can be used for single-sweep repetitive recording of transients up to 10 μs duration. e basic deflexion factor is 0·07 V/cm with a bandwidth of Mc/s or 0·2 V/cm with a bandwidth of 140 Mc/s, the low quency response being 3 db down at 1 kc/s. The time-se is generated by a modified boot-strap circuit with a ase inverter stage for balanced deflexion. Time-base rations of 0·1, 0·3, 1, 3 and 10 μs are available with a ce length of 4·5 cm. Provision is made for high or low pedance triggering with a stable voltage discriminator iable from 2 to 27 V. A paralysis circuit prevents re-ggering until a complete cycle of events (signal trace, ibration trace and camera operation) has been completed. e start of the trace occurs 30 mμs after the leading edge of trigger pulse. A wide-band trigger pulse amplifier is o included in the unit to enable the time-base to be trig-ed from the signal itself. Connexion to the *Y*-plates of tube can be made either directly, enabling a rise time of nμs to be displayed; or through a 140 Mc/s bandwidth tributed amplifier with a gain of 20 db and a rise time of nμs; or through a 70 Mc/s amplifier having a gain of 30 db d a rise time to 9 mμs. A 20 db pre-amplifier and a probe it are also available. Calibration markers are displayed a separate trace which occurs a short time after the signal ce. The *Y*-displacement of this trace is manually variable d the control is calibrated to allow amplitude measurements the range $\pm$50 V to be made. Markers are available at 02, 0·1, 0·2 and 1 μs intervals with a shift control to ilitate pulse length measurement. The markers are stable d accurate to 2%. A daylight loading 16 mm film camera n be attached to the front of the unit by means of four ews.

icro-spot cathode-ray tube. Ferranti Ltd., Hollinwood, Manchester, Lancashire.

new micro-spot cathode-ray tube capable of resolving 00 lines, is now available. Measuring five inches across, e 5/71CM tube, as it is known, has been developed for air-rne applications such as aerial mapping. The spot size is nsiderably less than one thousandth of an inch in diameter. ıe high resolution of the tube has been made possible by e use of an exceedingly fine screen and an entirely novel sign of electron gun. The gun uses two focusing elements, ıe of which is electromagnetic and external to the tube, ile the other is electrostatic and of fixed focal length.

The tube has an optical flat face with a non-darkening glass d a short cylindrical bulb, coated—except over the screen rface—with a thick layer of plastic resin, enabling it to be erated under adverse atmospheric conditions (for example, kV at 75000 ft without danger of e.h.t. breakdown). milarly, no tube socket is required, the leads to the rear end the tube being encapsulated in a way which does not hinder the tube from being mounted easily in its focus and scanning assembly.

While the new tube is primarily intended for the display or photography of repetitive information, single transients may be photographed at writing speeds which are limited by the scanning-coil requirements. The standard phosphor used in the tube has green fluorescence, decaying to 1/e level within ten microseconds after removal of excitation. It is also suitable for use with many types of photographic material. Tubes with a blue fluorescence can also be supplied.

Great care must be taken in considering the quality of e.h.t., scanning and focus supplies for the tube, because multiple effects resulting from e.h.t. ripple, imperfect focusing and poor scanning fields can cause such an enlargement of the spot that no advantage is apparent when using these tubes.

The firm can provide scanning and focus coils specially designed for use with the type 5/71 CM tube, together with a small alinement magnet which is clamped to the neck of the tube in the region of the cathode.

Cadmium sulphide photocell. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

This cell (type ORP11) is designed for end-viewing and has a circular sensitive element 12·7 mm in diameter. Its spectral response range extends from 0·5 to 0·8 μ, with maximum response in the yellow, red and near-infra-red regions.

Like the type ORP90, the first Mullard cadmium sulphide cell, the type ORP11 has an extremely high sensitivity and current-handling capacity, and will operate relays directly, with no intermediate amplification. It is inherently robust and operates from a.c. or d.c. supplies.

The chief applications of the ORP11 will be as a flame-failure detector in oil-fired burners. For some types of burner, and particularly those of the latest design, the end-viewing construction will be especially advantageous, because it enables the cell to be mounted compactly and with maximum convenience behind the inspection window at the rear end of the burner.

Other potential applications of the cell include industrial counting and detection equipment, lighting-control gear, smoke-monitoring apparatus, warning systems and safety controls, and, in fact, most kinds of photoelectric equipment designed to perform on-off switching operations.

Oscilloscope camera. Cardiac Recorders Ltd., 63, Weymouth St., London, W.1.

This camera, type 23A, has been designed to bridge the gap between galvanometer multi-channel recorders and normal 35 mm oscilloscope cameras. The magazine holds 50 ft of unperforated 60 mm recording paper, the whole width of which is available for recording. Two types of take-up cassette are available, a push feed for lengths up to 15 ft, and a power-driven cassette for up to 50 ft. Paper speeds of 0·02, 0·06, 0·2, 0·6, 2 and 6 in./s can be changed during a recording either by the speed-change switch or by electrical remote control.

A special feature of the camera is an automatic single-frame advance, facilitating the taking of single-sweep records. A built-in time marker exposes lines across part or the whole width of the paper at intervals of 1/25, 1/5, 1 and 10 s. Appropriate intervals are automatically selected by the spee change mechanism.

An *f* 3·5 bloomed lens with adjustable diaphragm focusing mount is fitted as standard, other lenses bein available. Operating values of supply voltage and frequen are as required.

New books

Electronic apparatus for biological research. By P. E. K. Donaldson. (New York: Academic Press Inc.; London: Butterworths Scientific Publications, 1958.) Pp. xii + 718. Price 120*s*.

This volume provides a most useful compendium for those biologists who are either obliged to provide and service their electrical apparatus or prefer to do so. It is indisputable that a worker entering the biological field will constantly be using apparatus such as thermostats, stimulators and counters; if he is to extract the optimum performance or to make a critical choice when buying an instrument he will be assisted by the content of this book. To profit from it requires little more than the mathematics involved in *L*, *C*, *R* circuits. By collecting together the formulae for input and output impedances of pieces of circuitry, and the attenuation and phase shift characteristics of various filters, time is saved even for those who have once had the results at their finger tips.

Practical points such as the cost per Wh of dry battery power, which lies between 1·5 and 83 d, are discussed. It is reasonable to find that little space is devoted to mechanical construction and internal layout because these are usually determined by existing facilities. A useful section deals with pickup at the input of high gain amplifiers and how to reduce it; this includes consideration of the artifact problem met when a stimulus pulse is fed into the specimen connected to the input. The author emphasizes that a radio frequency source inductively coupled to an isolated loop which includes a rectifier provides the best answer. Biologists are concerned with much more than electrophysiology and to broaden the interest of the book the main author has brought in contributions from others on such subjects as light sources, light measurement, radio-activity assay, temperature and humidity control, transducers and forms of electrodes. This last subject includes a summary of designs for micro-electrode pullers and techniques of filling the electrodes and measuring their resistance.

A chapter on transistors may serve to introduce these devices to those who have not yet made use of them. A few pages are devoted to the subject of "Faults" but methods for measuring component values and for checking valves are not discussed. It would perhaps be useful to devote more space to the subject of "Noise" (6 pages) since it is this in some form which should set the limit to measurements. The impedance converter with 100% feed back which is now commonly used in pH meters has as much claim to mention as say, infra-red sensitive cells but the author has made a reasonable compromise amongst the vast mass of material which might be included in his subject-matter. This book is to be commended to practically minded biologists.

E. J. Harris

Expansion machines for low temperature processes. By S. C. Collins and R. L. Cannaday. (London: Oxford University Press, 1958.) Pp. 112. Price 12*s*. 6*d*.

This is an account of the employment of expansion engines for the production of low temperatures beginning with the early work of Siemens and others on ice-making machine and ending with descriptions of the modern machines for th copious production of liquid hydrogen and helium, one well known example of which bears the name of the senior autho of this book. The treatment adopted is almost entirel descriptive, although the main portion of the book is precede by a short discussion of the essential thermodynamics. Th book should be of general interest to physicists but parti cularly to those responsible for the production of lo temperature facilities; although not intended as a desig manual there is a sufficient number of references to origi design articles.

R. Street

Analytical chemistry—Some new techniques. By A. G Jones. (New York: Academic Press Inc.; London Butterworths Scientific Publications, 1959.) Pp. vi + 267. Price 40*s*.

This useful book seems to be intended for the head of a analytical laboratory who is looking for new ways of analysi materials more quickly. It would also be useful to the teach of chemistry in a technical college or university, and to t instrument engineer in an industrial laboratory. In eigh quite separate chapters it reviews selected new techniques analytical chemistry in which considerable developments h taken place between 1950 and 1957. These are: flam photometry; differential spectrophotometry; gas chroma tography; the analytical use of ion exchange resins; acid-bas titrations in non-aqueous media; coulometric titrations differential refractometry; and the determination of oxyge and hydrogen in metals. The last section is subdivided int vacuum fusion methods and others. On the whole it is clea and concise, with adequate and contemporary bibliographie to each of the chapters.

E. van Someren

Mechanical properties of non-metallic brittle materials Edited by W. H. Walton. (New York: Interscienc Publishers Inc.; London: Butterworths Scientifi Publications, 1958.) Pp. xi + 492. Price 90*s*.

This volume is a record of the proceedings of a conference held in London in 1958, which was organized by the Minin Research Establishment of the National Coal Board in con sultation with the Building Research Station. As would b expected from its origin, the materials discussed are those c interest to the mining and building industries; resins an organic glasses are not included. Of the twenty-seven paper ten are concerned primarily with coal, six with concrete, fiv with rocks, four with glass and ceramic materials, one wit plaster and one with graphite.

Specialized interests are well covered, but the pape include a fair proportion which attempt to provide a basi interpretation of the phenomena of brittle fracture and ass ciated properties which will be of interest to physicists i other fields. Particular mention may be made of the paper b Evans and Pomeroy, which develops a statistical theory c fracture to account for the observed relations between size c specimen and breaking strength, the paper by Schiller on th

t of porosity on strength, the review by Miss Walton on
strength of glass, the study of the mechanism of rock
ure by Seldenrath and Gramberg, which discusses the
rkable phenomenon of longitudinal splitting under
ressive loading, and Davidson and Losty's paper on
on and graphite. The papers on the action of cutting
are also of considerable general interest both from the
retical and practical viewpoints.

contrast with the success which appears to have been
ved in the explanation of the fracture of such a complex
rial as coal, the apparent lack of progress on the subject
oncrete—judged by the papers in this volume—is dis-
inting. This subject appears to have got stuck at the
ing-and-dashpot" level. Whether this is due to its
rent difficulty or to an inadequate scientific effort on the
of the building industry is a matter for speculation.

hile most of the papers are very readable, some could
been improved by a few words of explanation of techni-
terms. How many physicists know the meaning of a
anced [explosive] charge" (p. 358) or are familiar with
gs" in bricks (p. 51)?

ith these reservations the book can be recommended.

L. R. G. Treloar

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chromatography 1958. Edited by D. H. Desty. (New
York: Academic Press Inc.; London: Butterworths
Scientific Publications, 1958.) Pp. xiii + 383. Price 70*s*.

book contains the proceedings of the 2nd Symposium
the Gas Chromatography Discussion Group of the
itute of Petroleum held in Amsterdam in May 1958. It
odies the important advances in gas chromatography
ch have taken place since the 1st Symposium held in
don two years previously. The 28 papers are divided
three sections: theory; techniques and apparatus; and
lications. The discussion which followed each paper is
n in detail and this adds considerably to the value of the
k. Interesting and important highlights include papers
the separation of very small samples, as emphasized by
possible use of capillary-coated tubes instead of packed
mns and by means of high pressure columns. Other
ers indicate that much work has been done concerning
rovements in existing detectors and the development of
ones with the increased sensitivity needed for small
mn loads. Some attention is wisely given to the
dardization of nomenclature and presentation of data.

n reading through this publication one is left with the
ression that there are few laboratories in university or
stry which cannot make use of the technique. I would
mmend this book as an important addition to the small
growing library on gas chromatography.

A. F. Williams

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laboratory equipment. 2nd ed. By L. G. Stang, Jr.
(Washington: United States Atomic Energy Commission,
1958.) Pp. viii + 429. Price $2.50.

s book takes the form of a well-illustrated descriptive
logue of remote handling equipment which has been
eloped in the U.S.A. for use with radioactive materials.
overs a wide range of both large and small scale applica-
s, and deals with many varying techniques.

ections of the book include ones on shielded enclosures
manipulators, and on viewing equipment which shows
gns of windows and optical equipment. Chemical pro-
ing equipment, and apparatus for measurement of
mical and physical properties of materials occupy a considerable part of the book. Other sections describe miscellaneous remotely operated machine tools and equipment for handling, transferring and storing samples. The remaining parts cover certain types of irradiation facility, and monitoring, decontamination and protective equipment.

In covering such a range, of necessity, only the immediate functioning of the items can be explained. Such specifications as are given are brief, but the numerous illustrations amplify the text admirably. The usefulness of the volume is in its presentation of the solutions which have been devised to meet the widely-varying problems arising in the remote handling field. Both newcomers and those familiar with active handling should find it educative. A potential user may well find a ready-made answer to his problem, and designers and manufacturers will find in its pages guidance and perhaps inspiration.

G. E. Lockett
J. Smith

The BEAMA catalogue. 4th ed. (London: Iliffe & Sons Ltd., for the British Electrical and Allied Manufacturers' Association Inc., 1958.) Pp. xvi + 840. Price £6.

The fourth edition of this catalogue serves as a useful buyers' guide to the products and services of the British electrical industry. It contains a five-language glossary in English, German, Spanish, French and Portuguese and is divided into sections under the following headings: Electrical power plant; Electrical equipment in industry, Transport and communications; Domestic and commercial electrical appliances, lighting, accessories and installation material; Classified buyers' guide; Trade directory; Index to illustrated catalogue pages.

British instruments, directory and buyers' guide. (London: Scientific Instrument Manufacturers' Association of Great Britain, and United Science Press Ltd., 1959.) Pp. 598. Price £2 2*s*.

A valuable new addition to scientific reference books is the new *British Instruments Directory and Buyers' Guide* which combines, in one volume, the information previously available in *British Scientific Instruments* published by the Scientific Instrument Manufacturers' Association and the *Instrument Directory and Buyers' Guide* published by the United Science Press Ltd. This new publication contains all the features of the two previous volumes and, in addition, is stated to have the full support of the instrument industry. The volume serves as a complete guide and handbook to all sources of supply of British instruments for science and industry together with their components and accessories. It is claimed that it contains references to all firms in the instrument and allied industry; it is not confined to those manufacturers who are members of the Scientific Instrument Manufacturers' Association of Great Britain. In addition to the classified lists of instruments and components, the book includes a four-language glossary in English, French, German and Spanish. The headings of the various sections are as follows: The Scientific Instrument Manufacturers' Association and other associations allied to the instrument industry; List of specifications directly bearing on instrument matters issued by official bodies; List of consultants, engineers and installers of instrumentation schemes; List of firms manufacturing single or small batches of instruments to a client's order; Classified index of products; Alphabetical list of instrument and component manufacturers with overseas agents; Trade names; Manufacturers' announcements.

Notes and comments

The late Mr. F. Twyman

This *Journal* does not publish obituary notices, but we are sure that our readers would not wish us to pass unnoticed the death of Mr. Frank Twyman who was associated with the instrument industry for over sixty years; he was 83.

He joined Otto Hilger in 1898, who succeeded Adam Hilger, his brother, and Twyman became Manager of the firm as long ago as 1902 and the first Managing Director of the Company when it was incorporated two years later. Among his important contributions to the optical industry were the invention and development of interferometers for testing.

He was elected a Fellow of The Institute of Physics in 1920 and served on its Board from 1925 to 1929 and 1930 to 1933 and was a Vice-President from 1936 to 1940. He was elected a Fellow of The Royal Society in 1924. He assisted this *Journal* in its early days in many ways, for which we are indeed grateful.

Twyman was a man who inspired respect and affection and was very human. He was good company and had a fund of excellent stories. Although in latter years he had not taken an active part in the scientific world, all who had the privilege of knowing him will greatly miss him.

Notes for Authors

The Institute of Physics has recently published a 36-page revised edition of its booklet intended to assist less-experienced authors and to serve as a reference booklet for all those who wish to contribute to the Institute's publications. Under its new title *Notes for authors*, it gives hints on the preparation of scripts and diagrams, on the layout of mathematics, the correction of proofs and so on. In addition to a bibliography of reference books and works on technical writing, the pamphlet also contains lists of the spellings, symbols and abbreviations used by the Institute. These conform with British Standard 1991: Part I: 1954: *Letter symbols, signs and abbreviations, Part I, General*, which authors of mathematical papers are also advised to consult.

Authors preparing contributions for submission to this *Journal* are invited to make use of the guidance available in the booklet, copies of which may be obtained from The Institute of Physics, price 3*s*. 6*d*. (including postage).

The annals of occupational hygiene

We have received a copy of the first issue of a new quarterly periodical entitled *The annals of occupational hygiene* produced under the editorship of Dr. C. N. Davies. This 134 page issue contains eleven papers devoted to different aspects of "Noise in Industry". The subscription price is £1 10*s*. or £2 12*s*. 6*d*. per volume to individuals for their personal use. The periodical is published by the Pergamon Press Lt 4 Fitzroy Square, London, W.1, for The British Occupation Hygiene Society.

Conference on magnetism and magnetic materials

The fifth conference on magnetism and magnetic materi will be held in Detroit, Michigan, 16–19 November, 1959.

Abstracts should be received by Mr. J. E. Goldma Scientific Laboratory, Ford Motor Co., P.O. Box 205 Dearborn, Michigan, by 25 August, 1959. Instructions authors as well as further conference details can be obtain from Mr. D. M. Grimes, Department of Electrical Enginee ing, University of Michigan, Ann Arbor, Michigan, U.S.A

Erratum

The units in the abscissa of Fig. 2 of the note by D. Ryley which appeared on p. 243 of the May issue of Journal should be mm × 10 and *not* mm × 10^{-1} as printed

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British Journal of Applied Physics

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NOTES AND NEWS

Notes and comments

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High-gain d.c. amplifier for biological purposes

By S. V. Hill, Department of Zoology and Comparative Physiology, University of Birmingham

[*Paper first received* 4 *September, and in final form* 23 *December*, 1958]

A "starved operation" d.c. amplifier is described, having a drift of less than 100 μV in 30 min, grid current less than 10^{-11} A and a noise level referred to the input of 15 μV with 10 MΩ grid resistors. Circuits are also described for using the amplifier with commercial cathode-ray and pen oscillographs.

eful d.c. amplifier for biological purposes must combine h gain with minimum drift. Its input stage must have h input impedance and grid current must be virtually it. Furthermore, non-microphonic operation of the stage is essential.(1–4)

e circuits described are based on the principle of ved operation" of the valve CV138.(5) They comprise a ced amplifier (Fig. 1) which is designed to be used with a de-ray oscillograph, the deflexion amplifier of which is ibed in Fig. 4. The maximum voltage gain of this ination is $1{\cdot}5 \times 10^6$. The drift amounts to not more 100 μV in 30 min and the grid current is less than A.

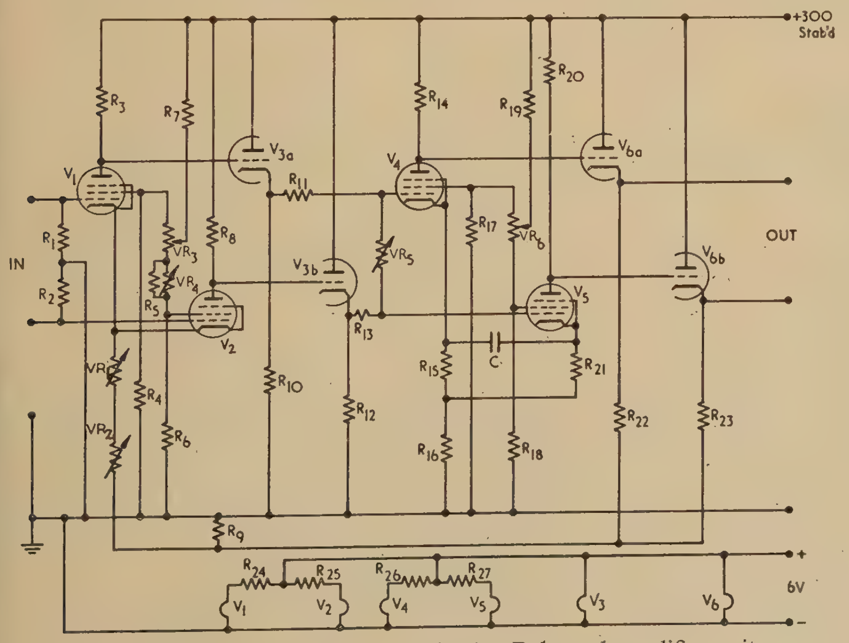
e amplifier may also be used with a pen recorder (the or used a four-channel pen recorder, the Electro-halograph by the Edison Swan Co. Ltd.) and the it for the necessary adaptor is described in Fig. 5. combination produces a pen deflexion of 1 cm/50 μV. use with a double-beam oscillograph (model 1049 by or Instruments Ltd.), a pre-amplifier of voltage gain as been designed and is described in Fig. 6.

THE AMPLIFIER (FIG. 1)

e following data were obtained from the amplifier under ational conditions: maximum voltage gain, 110 000; maximum output, ±40 V; maximum input, ±50 mV; noise referred to input, 15 μV with 10 MΩ grid resistors; noise referred to input, 5 μV with grids shorted to earth; discrimination against in-phase signals, 750 : 1; drift observed after 45 min, 100 μV/30 min; drift observed after 120 min, 50 μV/30 min; frequency response, 2 kc/s ($-1{\cdot}5$ dB); 5 kc/s (-9 dB); 10 kc/s (-18 dB).

The operating conditions chosen are a compromise to ensure low grid current with high gain and a useful frequency response. The use of high-resistance anode loads made it necessary to provide a cathode follower for each amplifier valve. The following operating data were found to be optimal: anode supply voltage, 300 V; anode current, 24–25 μA; screen voltage, 60 V; screen current, 7 μA; grid voltage, $-1{\cdot}5$ V; heater voltage, $5{\cdot}4$ V.

Circuit details. Valves V_1, V_2 have a voltage gain of about 1000. The cathode followers (V_3) ensure minimum loading and provide a low output impedance which permits the use of a simple gain control VR_5. Valves V_4, V_5 are provided with negative feedback by means of cathode resistors R_{15}, R_{21}. They have a voltage gain of about 110 at zero frequency, but at higher frequencies the capacitor C reduces feedback, thus improving the overall frequency response. Mean level feedback *via* R_{22}, R_{23} and R_9 to the common cathode return of V_1, V_2, stabilizes operating levels determined by the setting of the fine and coarse voltage level controls VR_1 and



R_1, R_2, R_3 = 10MΩ h.s.
R_4 = 120 kΩ h.s.
R_5 = 1 kΩ h.s.
R_6 = 120 kΩ h.s.
R_7 = 220 kΩ h.s.
R_8 = 10 MΩ h.s.
R_9 = 250 Ω w.w.
R_{10} = 50 kΩ h.s.
R_{11} = 47 kΩ h.s.
R_{12} = 50 kΩ h.s.
R_{13} = 47 kΩ h.s.
R_{14} = 8 MΩ h.s.
R_{15} = 56 kΩ h.s.
R_{16} = 750 kΩ h.s.
R_{17}, R_{18} = 220 kΩ h.s.
R_{19} = 180 kΩ h.s.
R_{20} = 8 MΩ h.s.
R_{21} = 56 kΩ h.s.
R_{22}, R_{23} = 100 kΩ h.s.

All high stability resistors ±5%. R_3 R_8, R_{11} R_{13}, R_{14} R_{20}, R_{22} R_{23}: paired 1%

R_{24}-R_{27} = 2 Ω constantan

VR_1 = 5 kΩ w.w.
VR_2 = 100 kΩ w.w.
VR_3 = 20 kΩ w.w.
VR_4 = 2 kΩ w.w.
VR_5 = 2 MΩ log
VR_6 = 20 kΩ w.w.

$C = 0{\cdot}0022$ μF

V_1, V_2 = CV138
V_3 = 6SL7
V_4, V_5 = CV138
V_6 = 6SL7

Fig. 1. Balanced amplifier unit

VR_2. With high impedance micro-electrodes, a cathode follower input(1) is used and, therefore, VR_2 is made large in order to accept an input voltage level ranging from zero to +3 V.

The procedure recommended for setting-up is as follows. Operate, with heater supply only, for at least 15 min; set all balance controls to centre of range; set the gain control at minimum, with no input signal and apply h.t. Set VR_2 to give required output level of 100–120 V; balance second stage VR_6; increase gain slightly and balance first stage VR_3; reset mean voltage level with VR_2 or VR_1. Further increase gain and balance with VR_3; increase to full gain, balancing with VR_4. Any alteration of gain setting will no longer affect the balance in the absence of an input signal. Adjustment of VR_4 should now be sufficient to correct any subsequent drift. All measurements involved in this setting-up procedure are carried out by means of the display or recording units used in conjunction with the amplifier.

To obtain valve stability it is necessary to age the valves for at least 200 hours. Fig. 2 shows the circuit used for ageing. It includes only one resistor and ensures that both voltage and current are kept within the limits of operational use in the amplifier. Ageing at "rated" operating conditions tends to result in high grid current.

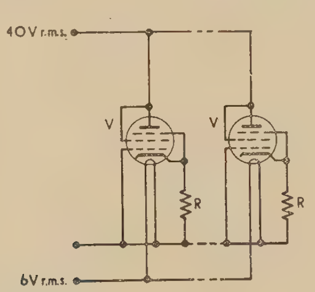


Fig. 2. Valve ageing

$R = 27\ \text{k}\Omega$

For valve selection a valve tester, Fig. 3, was designed which serves for comparison of valves under operat conditions.

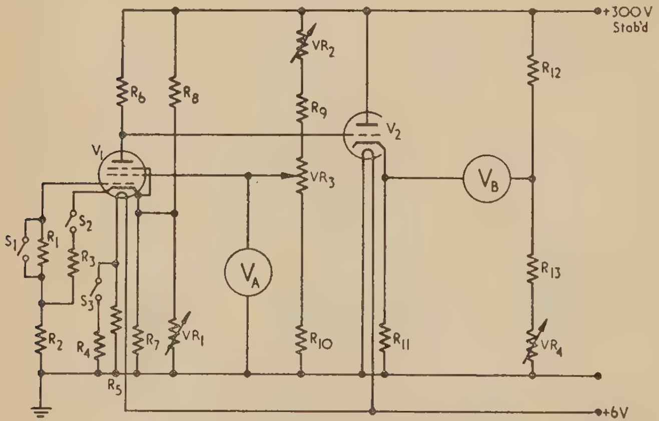


Fig. 3. Valve comparison circuit

$R_1 = 10\ \text{M}\Omega$ h.s.
$R_2 = 1\ \text{k}\Omega$ h.s.
$R_3 = 1{\cdot}5\ \text{M}\Omega$ h.s.
$R_4 = 120\ \Omega$ h.s.
$R_5 = 2\ \Omega$ constantan
$R_6 = 10\ \text{M}\Omega$ h.s.
$R_7 = 270\ \Omega$ w.w.
$R_8 = 47\ \text{k}\Omega$ w.w.
$R_9 = 33\ \text{k}\Omega$ w.w.
$R_{10} = 4{\cdot}7\ \text{k}\Omega$ w.w.
$R_{11} = 56\ \text{k}\Omega$ h.s.
$R_{12} = 47\ \text{k}\Omega$ w.w.
$R_{13} = 8{\cdot}2\ \text{k}\Omega$ w.w.

$VR_1 = 5\ \text{k}\Omega$ w.w.
$VR_2 = 1\ \text{k}\Omega$ w.w.
$VR_3 = 10\ \text{k}\Omega$ w.w.
$VR_4 = 2\ \text{k}\Omega$ w.w.

V_1 = CV138 (under test)
V_2 = ½ 6SL7

VA = 100 V full-scale
VB = 20 000 Ω per volt

S_1 = S.P.S.T.
S_2 = S.P.S.T.
S_3 = S.P.S.T.

It provides the following switches and controls:

(i) change of grid resistance for grid current estimati S_1: 10 MΩ;

(ii) change of grid voltage for comparison of gain, 1 mV;

(iii) change of heater voltage for comparison of drift, 10 mV;

(iv) control of screen grid voltage to satisfy the fixed cir conditions and to provide a voltage level from V_2 50 V.

The variable resistor VR_1 is pre-set to give a fixed bias −1·5 V in the absence of V_1, the valve under test; VR pre-set to give the required increment of 50 V suitable the lower ranges of the meter VB (say 45 V for centre sc of a 10-V range). Reference to anode voltage both in valve tester and in the two "starved" amplifiers imp measurement at the cathode of the associated cath follower, and neglects the difference between grid cathode potentials of V_2.

Checks made with the tester during ageing showed, du the first twenty hours, a reduction in grid current by a fac of between 10 and 100. There was also a conside increase in the screen voltage needed to maintain the an voltage of 50 V. The required screen voltage stabili logarithmically with ageing. The table shows the data six valves which were aged for 208 hours. Valves 1, 2 and 6 were chosen for use in the amplifier circuit as V_4, V_2 and V_3 respectively (Fig. 1).

Data for six valves aged for 208 hours

Valve No.	(*a*) V_{g2}	(*b*) μ	(*c*) *Drift*	(*d*) I_{g1}	*Fig.*
1	64·5	1·32	1·75	0·03	V_4
2	75·3	1·25	1·95	0·015	V_1
3	76·6	1·27	2·0	0·01	V_2
4	59·8	1·37	1·8	0·24	
5	63·8	1·35	2·1	0·02	(micro phoni
6	68·3	1·25	2·1	0·025	V_3

(*a*) Screen grid voltage setting for an output voltage le from V_2 of 50 V.

(*b*) Voltage gain expressed as a change of anode volt for an input change of 1 mV (S_2).

(*c*) Drift expressed as a change of anode voltage fo heater voltage change of 10 mV (S_3).

(*d*) Grid current expressed as a change of anode volt for a change of grid resistance of 10 MΩ (S_1).

DISPLAY AND RECORDING UNITS

The amplifier was designed to work with display recording equipment of several different types, which co be used either independently or in combination with osci graphs, tape recorders, or pen recorders. Equipment u in conjunction with the amplifier has to satisfy two conditi It must be able to supply a stabilized h.t. voltage of 30 at 10 mA for the d.c. amplifier, and its input stage must capable of coping with an output voltage level from amplifier of 100–120 V.

The circuit shown in Fig. 4 represents a deflexion ampli incorporated in the cathode-ray oscillograph. The switc is used in the setting-up of the d.c. amplifier and simply res centring of the trace for correct voltage level. A μ twin triode provides an effective voltage gain of 15 ing the combined voltage gain up to more than $\times 10^6$.

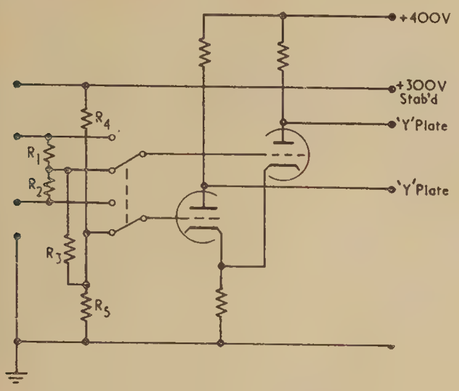


Fig. 4. C.R.T. amplifier

R_1, R_2 = 1 MΩ, 5%
R_3 = 1 MΩ, 5%
R_4 = 220 kΩ, 5 %
R_5 = 110 kΩ, 5%

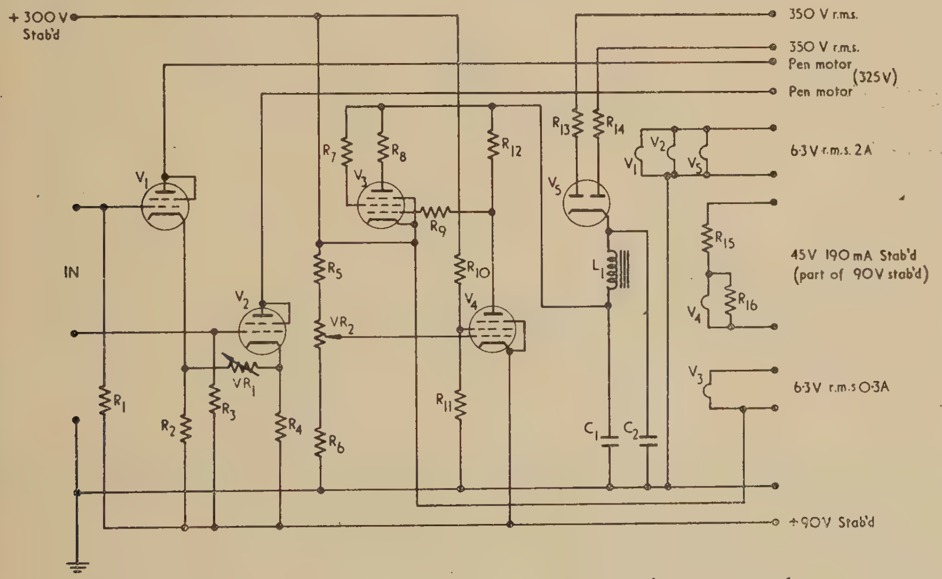


Fig. 5. Pen output stage and power supply

R_1 = 1 MΩ
R_2 = 820 Ω w.w.
R_3 = 1 MΩ
R_4 = 820 Ω w.w.
R_5 = 250 kΩ
R_6 = 33 kΩ
R_7 = 6·8 kΩ
R_8 = 100 Ω
R_9 = 1 kΩ
R_{10}, R_{11} = 56 kΩ
R_{12} = 250 kΩ
R_{13}, R_{14} = 270 Ω
R_{15} = 200 Ω w.w.
R_{16} = 470 Ω

VR_1 = 2 kΩ w.w.
VR_2 = 100 kΩ

C_1, C_2 = 16 μF

L_1 = 30H

V_1, V_2 = 6P25
V_3 = CV138
V_4 = 6AK5
V_5 = EZ80

e adaptor shown in Fig. 5 is used with the Ediswan r unit (E.P.P.) and pen oscillograph (E.P.R.). It plugs sockets provided on the power unit. Valves V_1, V_2 the pen motor, VR_1 varies the negative feedback loped in the cathode resistors R_2 and R_4 and, consently, the output impedance of V_1, V_2 for the critical ping of the pen motor. A meter in the power unit .P.) is used to set the combined anode current of V_1, V_2 0 mA. A stabilized supply of 300 V at 10 mA is derived n the 350 r.m.s. by means of V_3, V_4 and V_5. Valve V_5 capacitor input filter gives a smoothed voltage of roximately 450 V at the low current required, and pros adequate voltage across the series valve V_3. The ilized 90 V available from the E.P.P. unit provides a rence voltage for the control valve V_4. Forty-five volts 90 mA are available from the stabilized supply and are iced to 6·3 V at 175 mA by R_{15} and R_{16} to supply the er of V_4; V_1 and V_2 cathode returns are made to the 90 V line to reduce the total current drawn from the stabilizer (see the Ediswan E.P.P. and E.P.R. instruction manual). The overall gain of the amplifier (Fig. 1) plus the adaptor (Fig. 5) yields a pen deflexion of 1 cm/120 μV with critical damping. Since the pen motors do not respond to the higher frequencies, the capacitor C in Fig. 1 can be shunted with a resistor of 27 kΩ increasing the deflexion to more than 1 cm/50 μV.

Pen motor details. Coil, 1450 Ω centre tapped; sensitivity, 1 cm per 17·5 mA through whole coil; frequency response, 0–100 c/s with critical damping.

PRE-AMPLIFIER FOR USE WITH A COMMERCIAL OSCILLOGRAPH

Favourable experience with "starved valve" operation prompted the author to design the pre-amplifier in Fig. 6. It has a gain of 900 and can be used to great advantage in conjunction with a commercial oscillograph with built-in d.c. amplifier, having itself a gain of 900.

Operational data

Amplifier (*Fig.* 6). *S closed*

Voltage gain, 900; maximum input, ±25 μV; noise referred to input, 7 μV peak to peak; drift, less than 100 μV in 30 min (after warming-up for 45 min); frequency response, 2 kc/s (−2·5 dB); 5 kc/s (−8 dB); 10 kc/s (−12 dB).

S open

Voltage gain, 120; maximum input, ±160 mV; noise referred to input, 32 μV peak-to-peak; drift less than 700 μV in 30 min; frequency response 10 kc/s (−1 dB).

Circuit details. With switch S open, gain is reduced by negative feedback across cathode resistor. Capacitor C reduces impedance at higher frequencies, maintaining the frequency response to 10 kc/s. With S closed the bias is provided by $RV_{5a,b}$ from the heater supply. Variation in contact potential due to changes in heater voltage are mainly offset by changes in bias derived from the same source. Fine and coarse panel controls on each range are provided by VR_1–VR_2 and VR_3–VR_4 respectively. Batteries B_1 and B_2 are small layer-built deaf aid batteries, contained in the case.

Setting-up. With S open, set VR_1 to centre of range.

Adjust VR_2 for zero output voltage, close S, set VR_3 and VR_4 to centre. Adjust tap on $VR_{5a,b}$ for zero output; $VR_{5a,b}$ should now need no further adjustment, except possibly in the event of valve replacement.

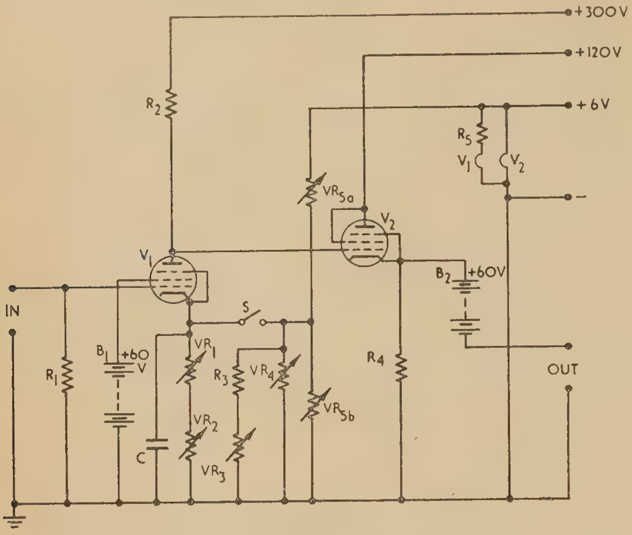


Fig. 6. Earthed input d.c. amplifier

R_1, R_2 = 10 MΩ h.s.
R_3 = 100 kΩ h.s.
R_4 = 82 kΩ h.s.
R_5 = 2 Ω constantan

VR_1 = 5 kΩ w.w.
VR_2 = 50 kΩ w.w.
VR_3, VR_4 = 20 kΩ w.w.
VR_5 = 5 kΩ w.w. adj. tap.

C = 0·0015 μF

V_1 = CV138
V_2 = 6AK5

B_1 = 60V deaf-aid
B_2 = 60V deaf-aid

S = S.P.S.T.

NOTES

The type CV138 valves used were of several different makes, but were found to have equivalent characteristics. They are available as types 6AM6, 8D3, Z77, EF91, and also available in special quality versions 6064, F/6064 w "flying leads." The 6 V heater supply was provided by th plate lead-acid accumulators of 60 A-hours actual capac These were used in all tests, beginning at about three-quart charged condition.

As grid current is increased by photoelectric emissi valves were screened from external light at all times. T valves having low heat dissipation, no ventilation was p vided in the amplifier cases. This also reduced drift due rapid external temperature fluctuations and excluded external light.

Considerable care is required to ensure freedom fr microphonic effects. The chassis were therefore ligh mounted on springs, and connecting leads to panel contr and terminals were made of thin flex.

Reliable performance depends on good heater supply. I low tension switches were used and all connectors w soldered.

ACKNOWLEDGEMENTS

The amplifier and auxiliary equipment was designed in t Department of Zoology and Comparative Physiology in t University of Birmingham, and I am indebted to Prof. O. Lowenstein for his encouragement and advice.

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Method for measuring the moisture content of air

By J. Higgins, B.Sc.,* Mining Research Establishment, National Coal Board, Isleworth, Middlesex

[*Paper first received* 14 *January, and in final form* 20 *February*, 1959]

The water vapour in a sample of air is first condensed as ice and subsequently allowed to evaporate at room temperature, so causing a pressure rise in a closed, evacuated system, the pressure being measured by a simple oil manometer. The apparatus for doing this is described in detail and, by a calibration of the instrument with known masses of water vapour, a factor can be obtained that converts the observed vapour pressure to absolute humidity with an overall accuracy better than 1%. The apparatus has also been used to study the relationship between water vapour pressure e (mm of mercury) and absolute humidity h_v(g/m^3). A value of 286·4 ± 1·7 was obtained for the constant C in the equation $h_v = Ce/T$ where T was the absolute temperature (° K).

The work described in this paper arose from the need in the mining industry for an accurate method of determining the moisture content of air in underground workings. In these conditions, and in similar dusty conditions elsewhere, the normal methods of measuring moisture content, most of which depend on an interaction between a moist surface and the atmosphere to be measured, are suspect owing to fouli of the surface.

The present method makes use of the Micro-moistu determination apparatus (by Edwards High Vacuum Lt which was designed for the measurement of the moistu content of solid samples. The procedure is to take a samp of the atmosphere in a small glass flask, freeze out t moisture in the sample, pump out the dry air and th measure the vapour pressure of the re-vapourized moistur method has the advantages that the volume of the ›le does not need to be measured, and that the effects ›sorption on the inner surfaces of the apparatus can be ıated by means of an absolute calibration of the ument.

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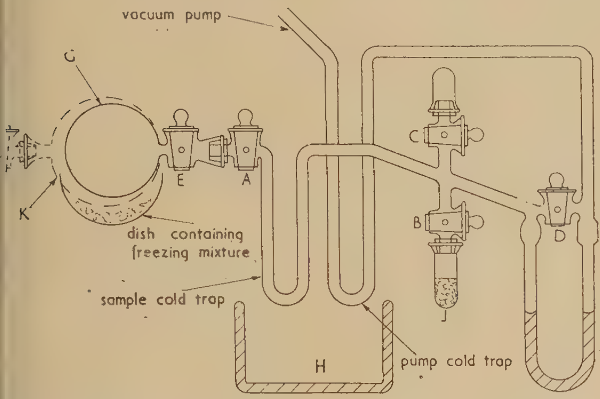
* Now at Armament Research and Development Establishment, Quebec, Canada.

USE OF THE APPARATUS

ıe figure shows a diagrammatic sketch of the apparatus. n be evacuated by a Metrovac type D.R.1.H. pump (by ropolitan-Vickers Electrical Co. Ltd.) fitted with a



iagrammatic layout of the moisture determination apparatus

sture trap. The sample flask *G* is connected to a measur- section *A–D* containing a cold trap. The measuring ion can be connected either directly or through a erential oil manometer to the pumping section which contains a cold trap. Either or both of the cold traps be immersed in a freezing mixture of solid carbon dioxide methylated spirits contained in a Dewar flask *H*.

he sampling flask *G* is prepared for use by connecting it l by means of a B 10 cone joint. With all taps open, the k and apparatus are evacuated and, after removal of the n mass of air and water vapour, the Dewar flask is raised r the pump cold trap. That any moisture originally in flask has been completely removed can be checked during austion by moving the Dewar flask to enclose both cold ›s. After a few minutes, taps *A* and *D* are closed, the var flask is moved to cover the pump cold trap only, and sample cold trap is allowed to regain room temperature. oil manometer will indicate the presence of moisture, if . Sampling flasks, when prepared in this way, can be ed for two or three days with no appreciable leakage of sture into them.

flask, when filled with a sample of the air of which the sture content is to be measured, is connected to the aratus as before, keeping tap *E* closed. The bottom of flask is immersed in a freezing mixture of methylated its and solid carbon dioxide, contained in a wide-mouthed ı. While the moisture is being frozen in the flask, the of the apparatus up to tap *E* is evacuated *via* the pump l trap, removing both air and moisture from the apparatus. kage at the cone joint and moisture removal can both be ked by means of the differential manometer.

fter sufficient time has elapsed for the freezing of the sture in the sample and moisture removal from the ainder of the apparatus—about ten minutes—the Dewar k is moved to cover both cold traps, tap *E* is opened and the flask is evacuated. When the limiting pressure is reached (equal to or less than 0·02 mm of mercury) taps *D* and *A* are closed and the sample cold trap and flask are allowed to regain room temperature. The pressure indicated on the differential manometer when the sample cold trap regains room temperature is a useful check on the efficiency of the freezing of the moisture in the sample flask. Normally, the pressure indicated is of the order of 0·02–0·06 cm of oil, corresponding to a water vapour mass of $1{\cdot}3$–$3{\cdot}9 \times 10^{-7}$ g. The efficiency of the sample cold trap in extracting moisture under flow conditions is approximately 70%, so that the amount of moisture lost during evacuation is about $1{\cdot}0 \times 10^{-7}$ g, which is less than 0·01% of the mass of water in a sample. When room temperature has been regained tap *A* is opened and the reading on the differential manometer is noted as e_1, and the room temperature is also noted. Tap *E* is closed and the moisture in the measuring section is removed through tap *D*. Tap *D* is closed again, tap *E* opened and the new manometer reading is noted as pressure e_2. The procedure is repeated to give pressures e_3, e_4, etc.

The initial vapour pressure of the moisture in the sample flask is required, and this is obtained in the following manner. Let V = volume of the sampling flask, v = volume of measuring section between taps *E* and *D*, and e_0 = initial water vapour pressure in the flask.

Then
$$e_1 = [V/(V+v)]e_0$$
$$e_2 = [V/(V+v)]\,e_1 = [V/(V+v)]^2\,e_0$$
and generally
$$e_n = [V/(V+v)]^n e_0$$
Therefore
$$\log e_n = \log e_0 + n \log [V/(V+v)]$$

When $\log e_n$ is plotted against n a straight line is obtained, and extrapolation back to $n = 0$ gives a value of e_0 without any knowledge being required of the actual volumes of the sampling flask or measuring section. If it is desired to alter the volume of the measuring section it can be increased by opening tap *C*. If the presence of condensable vapours other than water is suspected, the water vapour can be absorbed in the phosphorus pentoxide trap *J*, and the residual pressure, if any, subtracted from the pressure e_1. The trap *J* has, of course, to be evacuated initially and the tap *B* closed.

The procedure described takes about thirty minutes to carry out in the laboratory.

CONSISTENCY OF THE APPARATUS

The consistency of the apparatus was checked by measuring the vapour pressure of identical atmospheric samples with the apparatus. To obtain such samples, two evacuated sample flasks were connected to a T-piece tubing. The assembly was then placed in a chamber in which the air was well mixed by means of a circulating fan to give uniform vapour pressure, which was determined from the readings of an Assmann psychrometer installed in the chamber. The flasks were filled through a tap on the third limb of the T-piece. After filling, the tap was closed but the two flasks were left in communication with each other for some time before the flask taps were closed and the water vapour pressure in each was determined.

Typical figures for a series of measurements are shown in Table 1. Temperature corrections have been applied where the air temperature at the time of taking the sample differed from that at the time of measuring it.

The average difference in relative humidity between flasks, calculated from the air temperatures and measured vapour pressures, was 0·15%. In practice there would be an additional error in the measured relative humidity as a result of any error in reading the air temperature. At the ambient temperatures used in the above tests (about 21° C), an error of ±0·05° C would result in an error of ±0·12% in the relative humidity.

Table 1. *Results of a series of tests of consistency*

	Determined vapour pressure (mm Hg)			
		By present method		
Test	*From Assmann readings*	*Flask* 1	*Flask* 2	*Difference between flasks* (%)
1	6·4	6·46	6·50	0·6
2	7·1	6·93	6·91	0·3
3	—	7·29	7·24	0·7
4	5·6	5·93	5·86	1·1
5	—	9·86	9·86	nil

Average percentage difference between flasks 0·5

ABSOLUTE CALIBRATION

A flask and tube (K and T respectively in the figure) replace the sampling flask. The flask is a 1000 cm^3 separating funnel, with a B 10 socket on the stem for attaching it to the measuring section. The tube is made from a stopcock, with one arm closed and a B 19 cone on the other arm for connecting it to the flask. It is cleaned carefully to remove all grease from the cone, and is then weighed before and after a quantity of water, about 100 mg, is introduced into it by a hypodermic syringe. The difference between the weights gives the mass M of the added water. The tube is connected to the flask, the water in it is frozen by means of a dry ice mixture, and the apparatus is evacuated in two stages. First, the measuring section and flask are cleared of air and moisture up to tap F, and then, with the specimen cold trap at dry ice temperature, the tube is evacuated. Thus, any moisture lost from the tube during evacuation is retained in the measuring section.

When the limiting pressure is reached (equal to or less than 0·02 mm of mercury), tap D is closed, an unknown mass m of the water in the tube is allowed to leak as vapour into the flask, and the vapour pressure exerted by this mass of water in the volume between taps E and F is determined in the normal manner. The ambient temperature is also measured. This water vapour is then removed from the apparatus and the process repeated till the total quantity M of water in the tube has been used. During the final filling of the flask fro the tube, the tube is heated to ensure that no film of wa remains.

The volume V of the flask between taps E and F is dete mined accurately by filling with distilled water and weighin

If h_v = absolute humidity, i.e. water content in u volume (g/m^3), e = vapour pressure (mm of mercury), a T = absolute temperature (° K) then

$$h_v = Ce/T$$

where C is a constant and

$$m = h_v V = CeV/T$$

Therefore, the total mass of water,

$$M = \Sigma m = CV\Sigma\frac{e}{T}$$

The constant C can then be determined from the measur values of vapour pressure corresponding to each succes fraction of water. Table 2 gives the results of one series an ambient temperature of 21° C.

Table 2. *Absolute humidity calibration factor*

Test	*Mass of water* M (g)	$\left(V\Sigma\frac{e}{T}\right)10^3$	$C = M/V\Sigma\frac{e}{T}$
1	0·0430	0·1489	288·6
2	0·0611	0·2148	284·4
3	0·1078	0·3747	287·7
4	0·0852	0·2989	285·0
5	0·0910	0·3180	286·1
			Average 286·4 ± 1

From the values of saturation vapour pressure and absol humidity published in the Handbook of Chemistry an Physics* a value of 286 can be calculated for C at a temper ture of 21° C, which is in good agreement with the val obtained here and indicates that absorption effects are smal The value of 289 recommended in Brit. Stand. 1339: 194 which is obtained from the equation of state for an ideal ga could give an error of 1% in the determination of absolu humidity.

ACKNOWLEDGEMENTS

The author acknowledges the helpful advice received fro Mr. C. Jones, who directed the work as part of the researc programme of the Scientific Department of the National Co Board. The work is published by permission of the Director General of Research.

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* *Handbook of Chemistry and Physics*, 36th ed., pp. 2142 an 2296 (Cleveland, Ohio: Chemical Rubber Publishing Co., 1954).

Integrating exposure meter for electron microscopy

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[*Paper first received* 28 *January, and in final form* 11 *March,* 1959]

Guesswork in estimating the correct exposure of photographic plates in electron microscopy is wasteful of time and materials. The integrating meter described depends upon the scattered X-ray emission from the plate being exposed, and ensures correct exposures under diverse conditions. The instrument has proved stable and reliable in operation.

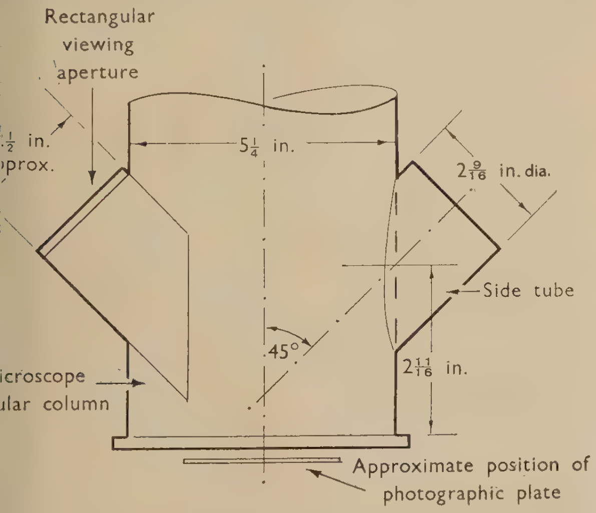
sure meters are much less widely used in electron graphy than in normal photography. The reason seems that many electron microscopists are able to operate fairly constant conditions with little need for variation posure times. Exposures have been estimated by some ers by measuring the light emitted from a fluorescent n inside the microscope. Because of ageing of the n (with consequent reduction in light output) measures by either photometric or comparative methods are to error.

e criterion for deciding the usefulness of an exposure is that the time required to operate and maintain it d be less than the wastage of time that would have ed from incorrect exposures. The wastage of time and ial from incorrect exposure is least where one operator s under fixed conditions and greatest where a number ferent operators work under varying conditions. The n requirements were therefore:

that the system should be simple, free from drift and should need no adjustment after initial calibration;

that the indication should be unaffected by any conditions of room lighting.

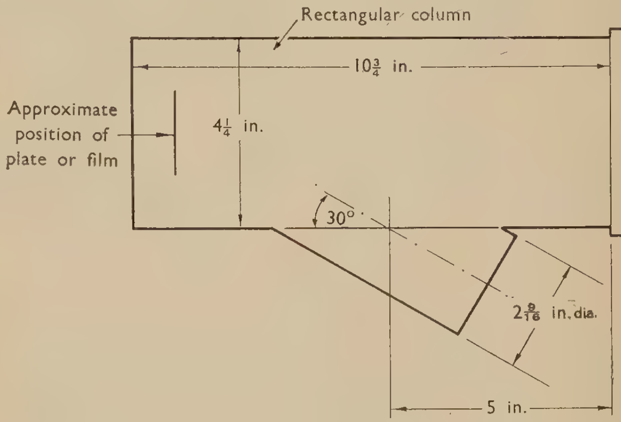
e have been achieved in a design that integrates total sure (intensity × time) whilst the plate is being exposed provides a continuous visual indication corresponding e ultimate blackening of the developed plate. Integra- commences when the shutter is opened, and the shutter sed at the appropriate reading on a meter scale. The ation method was adopted so that no time need be on the measurement of screen brightness. Further, electrical integration is very simply achieved by charging a capacitor, the design called only for the selection of one of a number of available methods for converting the energy flux at the image into a voltage or current. It was difficult to predict the long-term stability of the various possible methods, several of which might have been satisfactory. The method finally selected was to collect X-ray pulses from the plate emulsion with a Geiger counter tube and apply these to a count-integrator circuit.



[Crown Copyright.]

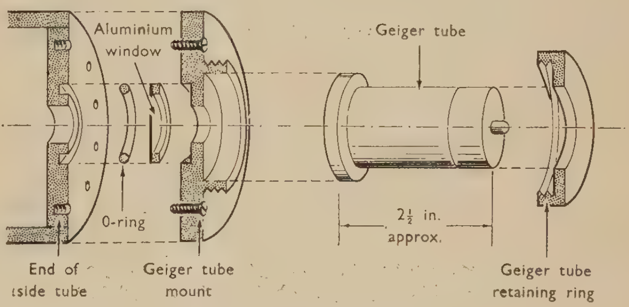
. 1. Mounting of side tube on column of electron microscope, type EM3

The apparatus as described was designed for use with Metrovick electron microscopes types EM3 and EM4 (by Metropolitan-Vickers Electrical Co. Ltd.), but may be adapted for use with any type. Figs. 1 and 2 show the attachment of the side tube to the EM3 and the EM4 respectively. The mountings of the aluminium windows and Geiger counters on the tubes are shown in Fig. 3. The positions of the Geiger tubes on the microscopes enable them to receive X-rays from all parts of the photographic plates.



[Crown Copyright.]

Fig. 2. Mounting of side arm on column of electron microscope, type EM4



[Crown Copyright.]

Fig. 3. Details of Geiger tube mounting

The circuit of the exposure meter is shown in Fig. 4. Pulses from the anode of V_1 are applied to the diodes V_{2A}

and V_{2B} by the capacitor C_1. The diodes are connected so that the current charging C_1 flows through V_{2A} whilst the discharge current flows through V_{2B}. This current then charges the capacitor C_2, which is connected between the anode of V_{2B} and earth. In this manner, the pulses produced by V_1 are integrated, and potential differences appearing across C_2 are applied to the pentode section of V_3, the amplifier of a valve voltmeter.

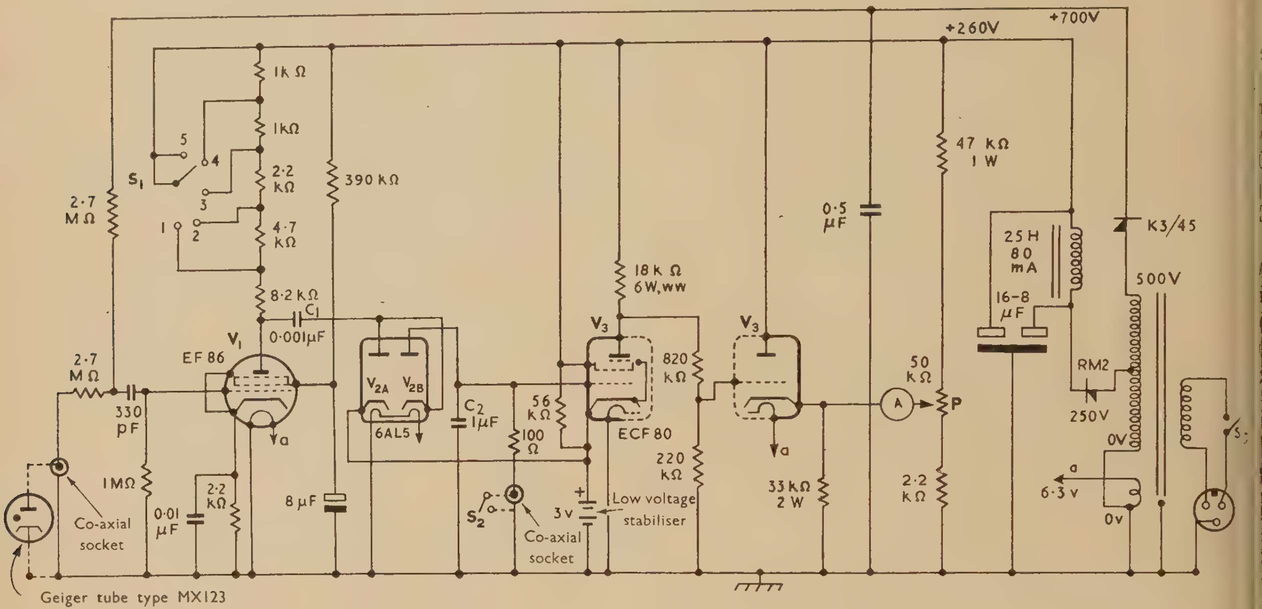


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Fig. 4. Circuit for electronic exposure meter

Drift of the meter zero is completely eliminated by connecting the cathode of V_{2A} to that of the following pentode, which is maintained at +3 V, by a low-voltage stabilizer. Backing-off of the diodes in this manner ensures that only the required signals charge the capacitor C_1.

The triode section of V_3, together with a potential divider connected across the h.t. supply, form a Wheatstone bridge, in which a milliammeter (0·1 mA full-scale deflexion) is the indicator. Component values in the bridge circuit were chosen so that overloading of the valve voltmeter would not damage the milliammeter.

The switch S_2 is mounted externally to the instrument and may be mechanically coupled to the electron-microscope shutter. S_2 is normally closed to form a short-circuit across the integrating capacitor and, in this condition, the meter bridge is balanced, so that the meter reads zero. The switch is opened at the beginning of exposure and the charge on capacitor C_2, increasing in proportion to the number of X-rays triggering the Geiger tube, results in a rising deflexion of the milliammeter.

The relationship between meter reading and emulsion blackening of the photographic material is determined initially by making a series of graded exposures, and the sensitivity control S_1 is usually set so that a mid-scale meter reading is obtained for the exposure time normally u (10–15 s). Component values associated with S_1 w chosen to cover a range of emulsion sensitivities of 16

The instrument is isolated from the mains by a transform the low-voltage secondary winding of which supplies po to the valve heaters and to a lamp illuminating the scale the milliammeter. One end of the high-voltage second winding is connected to the chassis, so that two separate hi voltage supplies are obtained from the half-wave rectifie One of these provides about 20 mA at 230 V for valve an circuits, while the output from the other provides a curr of a few microamperes at 650–700 V to meet the requireme of the Geiger tube.

It should be noted that this method measured avera image intensity, and images with large, dark areas might c for reduced exposure times. No corrections have been fou necessary, however, for powder specimens or for a numb of metallurgical replicas examined.

The overall stability of the apparatus is such that with t capacitor C_2 short-circuited, the maximum drift obser over a testing period of 5 days was less than one-twenti of full-scale deflexion of the milliammeter. Some drift occ during exposure of the photographic plate in the electr microscope, and is caused chiefly by stray radiation. T average rate is about 1 count per second, and is only importance if very long exposures are made. The syst has so far operated daily for over a year without apprecia change in calibration.

Detailed drawings of the components added to the mic scopes may be obtained from the Safety in Mines Resear Establishment. This paper is published by permission of Ministry of Power.

Photoelectric apparatus for measuring velocity

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[*Paper received* 22 *December*, 1958]

An apparatus is described which uses photoelectric means for measuring velocity. The apparatus caters for projectiles 1–5 cm in diameter with velocities of 700–3500 cm/s. The accuracy of measurement is approximately ±0·2%.

velocity-measuring apparatus was designed for use with lopkinson Pressure Bar apparatus.*† However, its use ch more general, and a description of the instrument is ;ht to be of interest.

iginally, the momentum of the timepiece of the :inson Pressure Bar apparatus was measured by a tic pendulum. In Australia, in 1945, this was replaced he direct measurement of velocity by a counter-ıograph method, with a mechanical system of triggering strips of tinfoil as start and stop contacts. After ience with this mechanical system it was considered further improvements would result from the use of a ɔcell triggering device.

DESCRIPTION

e arrangement is shown diagrammatically in Fig. 1. s flight, the timepiece (1–5 cm in diameter) intercepts

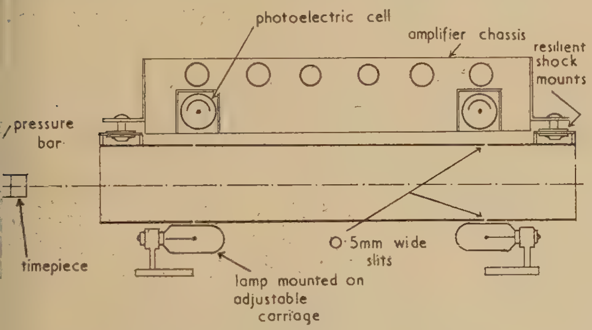

Fig. 1. Velocity-measuring apparatus

parallel light beams which are set 25 cm apart in a tunnel :m square. Each light beam is formed by slits 0·5 mm and 1 cm long perpendicular to the trajectory. A rate exciting lamp, photocell and amplifier are used for interception.

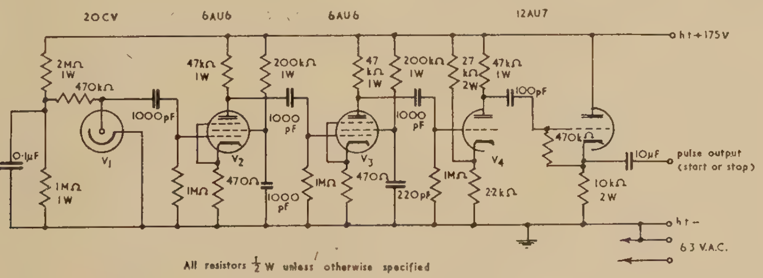

Fig. 2. Circuit diagram of photocell and amplifier

The lamps chosen are of the kind commonly used for the reproduction of sound from film and have coiled filaments about 0·5 mm in diameter and 1 cm long, which match the slits. They are mounted on adjustable carriages, and are alined to illuminate the top slits.

When the light beams are intercepted, pulses are produced which operate the trigger circuits at the counter-chronometer input. Because these pulses are transmitted over about 20 ft of cable, a cathode-follower output is required for the amplifier. Vacuum photocells are preferred to gas photocells because of the necessity for obtaining a fast response.

A three-stage amplifier with an overall gain of 1400 times is employed. This gives more than enough voltage to trigger the counter chronometers even with the lamps operating below their maximum rating. A large reserve of sensitivity is thus assured.

For timepiece velocities of 700–3500 cm/s, the required frequency response is 14–70 kc/s, which is well within the bandwidth of the amplifier. The response of the amplifier at 100 c/s is so low that alternating current may be used to heat the lamp filaments, and no serious addition is thereby made to the hum level of the amplifier.

The triode stage of the amplifier (Fig. 2) is over-biased, thus requiring a certain minimum signal to produce an output pulse. This will cause a sharp discrimination against the generation of a pulse when the projectile does not traverse the apparatus close to the longitudinal axis, and has the advantage of tending to prevent measurements when the proper trajectory is departed from laterally.

To avoid trouble from vibration, the amplifiers were mounted on resilient shock mounts, and the whole unit on larger shock mounts. The light slits were accurately set out and milled through both top and bottom shields together. At the same time, an extra sheet was milled so that it could be used as a shutter to cut off the beams simultaneously. The amplifier photocell assemblies are on a common chassis which can be reversed in the body of the instrument. Any disparity in amplifier delay can be shown as a difference in counter-chronometer reading on operating the hand shutter with the amplifiers first in one position and then interchanged. It was shown that, to within ±5 μs, each amplifier

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Hopkinson, B. *Phil. Trans Roy. Soc.*, **213**, p. 437 (1914).
Robertson, R. *Trans Chem. Soc.*, **119**, p. 1 (1921).

contributed the same delay. It may be presumed that if the shutter could be moved as fast as the timepieces, the amplifier-delay errors would be reduced. However, it is not possible to use this shutter at such a high velocity.

ACCURACY

The absolute accuracy of the instrument is limited by the accuracy with which the slits are set out. In the present apparatus, the distance is known to be 25 cm to within 1 part in 10 000. The biasing arrangements and circuit design are such that the error in recorded velocity will rarely be worse than 0·2% and will usually be about 0·1%.

TESTING OF APPARATUS WITH HOPKINSON PRESSURE BAR

A tandem arrangement for measuring the velocity of the timepiece was set up. The mechanical contactor was placed first in the line of flight, the front foil being 5 cm from the timepiece, and the front light beam being 15 cm beyond the second foil contact, that is, 45 cm from the timepiece. It was arranged in this manner to facilitate adjustment of the foil height early in the trajectory.

The apparatus was carefully alined so that, with the axis of the pressure bar perpendicular to the planes of the light beams, at least half of each beam was obscured by the timepiece in flight.

Tests were made using seven different types of detonator on three types of pressure bar. Timepiece velocities ranged from 700 to 3000 cm/s. In all cases a higher velocity recorded by the photoelectric apparatus, the average differ being 4 cm/s. There is every reason to believe that approaches very closely to the true velocity because it been shown that the mechanical arrangement would velocities consistently lower by up to 0·4%. In general, coefficients of variation were slightly lower for the ph electric apparatus.

OTHER APPLICATIONS

The primary function of this device was to measure time of flight of pressure bar timepieces, but it may be for measuring the velocity of other objects. Its freque response has permitted its use for the measurement of velocities of spheres rolling in a glass tube (where the velo has been as low as 200 cm/s) and of cylinders proje from an air gun (at velocities up to 10 000 cm/s).

FUTURE IMPROVEMENTS

A unit fitted with four photoelectric cells arranged in pairs each slightly offset from the tunnel centre is being to give duplicate readings. Amplifying systems will not made interchangeable, but provision will be made for tes each photocell system by means of a rotary light choppe

ACKNOWLEDGEMENTS

This paper is published by permission of The Chief Scie Australian Defence Scientific Service, Department of Su Melbourne, Australia.

High energy, high current synchrotron injector

By G. R. Davies, B.Sc., Ph.D., Physics Dept., University College, London, and P. R. Chagnon, M.Sc., Ph.D., Physics Dept., University of Michigan, U.S.A.

[*Paper received* 4 *February*, 1959]

The construction and testing of a pulsed 450 keV injector for an electron synchrotron are described. High voltage is obtained with a spark gap and pulse transformer. The electron-optical system consists of a series of electrodes connected to a voltage divider programmed so as to approximate the field in a space-charge-limited plane diode. Quadrupole lenses are used to optimize the shape of the beam spot and to counteract space-charge spreading. Details are given of the dependence of beam current on energy and on filament power.

In electron synchrotrons which make use of betatron action during the early part of the acceleration cycle, it is usually sufficient to inject electrons at an energy of 100 keV or less.⁽¹⁾ The Michigan race-track synchrotron, however, employs frequency modulation of the radio-frequency accelerating oscillator, the frequency being increased continuously from injection time until the circulating electron beam has become strongly relativistic. In such an accelerator a rather higher injection energy is desirable in order to reduce (*a*) the amplitude of the phase oscillations immediately following injection, and (*b*) the frequency range required of the radio-frequency system. In addition, the acceptance time is comparatively short (approximately 1 μs). Consequently, the injection requirement is for a short, high-current, high-energy pulse of electrons.

The injector described herein is capable of operating at 450 keV and delivering a maximum pulsed beam current of 1 A. A pair of quadrupole magnets permits adjustment of the shape of the beam cross-section to the optimum for synchrotron acceptance.

GENERAL DESCRIPTION

(*a*) *Design considerations.* Ideally, in order to produc parallel beam of electrons limited in intensity only by sp charge (within the thermionic emission limit of the cathod it is necessary to provide a field distribution of the infin planar diode form. Thus for a direction of motion $E_z = kj^{2/3}z^{1/3}$, where E_z is the z-component of electric fi intensity, k is a constant and j is the current density.

(Relativistic considerations have been deliberately igno in the design of this injector. In principle, a more nea uniform gradient is required relativistically. However, of the classically-calculated gradient results in a slight c striction of the beam toward the end of the accelerat column, and this was felt by the authors to be a desira effect.)

This is exactly as in the Pierce electron gun.⁽²⁾ In present application, the use of only two electrodes would inconvenient because of the correspondingly large diame needed for a reasonable aspect ratio. Accordingly, the id distribution is approximated by means of a stepwise arran

, in which a larger number of plates is used. The rations of these plates decrease suitably as z increases, iat with equal increments of voltage across each pair the increases approximately in accordance with the above irements. The cathode electrode is conically shaped rding to the Pierce specification, since the flat plate oximation would be poor in this most important region.

) *Cathode and accelerating column.* The components of cathode and accelerating column assembly are shown in 1. The cathode consists of a directly heated filament F

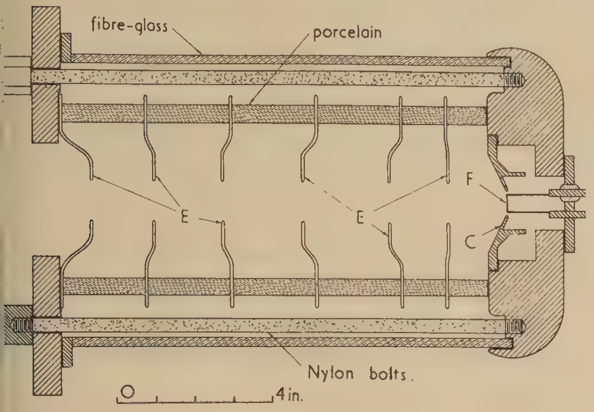

Fig. 1. Cathode and accelerating column

filament; C, conical cathode electrode; E, electrodes. ater is circulated in the space between the porcelain ulators and the fibre-glass jacket. Gaskets, screws, etc., are omitted for the sake of clarity.

·020 in. thoriated tungsten wire wound in the form of a double spiral, approximately 0·4 in. outside diameter. two ends of the filament are brought out normal to the e of the spiral and held in small screw clamps on a nting plate. Replacement is thus a simple process.

ie electrons emitted by the filament are accelerated down electrode system. This consists of six aluminium plates parated by porcelain ring-shaped insulators, the assembly ates and insulators being cemented together. Each plate in. in diameter and 0·080 in. thick and has a central 1 in. in diameter through which the beam passes. ral smaller holes nearer the edge of each plate facilitate ping, the interior of the column being maintained under vacuum of the order of 10^{-6} mm of mercury. The elain rings are 5 in. outer diameter, 4 in. inner diameter either 1·12 or 2·24 in. long according to their position ie column. Thus the cathode, first plate and second have single space separation, and the other plates ole.

ie filament mounting plate is attached to the back plate ie assembly, and so locates the filament in the central of the conically-shaped cathode electrode C.

ie accelerator column is enclosed by a fibre-glass cylinder hat demineralized water can be circulated around it. jacket of water serves as a voltage divider for the lerating electrodes, and at the same time provides cooling he cathode assembly. The accelerating electrodes are -shaped by different amounts in order to provide the ired increasing increments of electric field strength along ixis.

iis accelerating assembly is supported horizontally in a sure vessel approximately 4 ft long and 18 in. in diameter ch also contains the high-voltage pulse transformer. A ure of Fréon-12 (by Kinetic Chemicals Inc., Wilmington, U.S.A.), nitrogen and carbon dioxide is maintained in the tank at a pressure of about six atmospheres.

(*c*) *The high-voltage pulse supply.* The pulse transformer system, indicated schematically in Fig. 2, is similar to that generally in use with betatrons; the particular pulse transformer design used here allows operation at 500 kV or more,

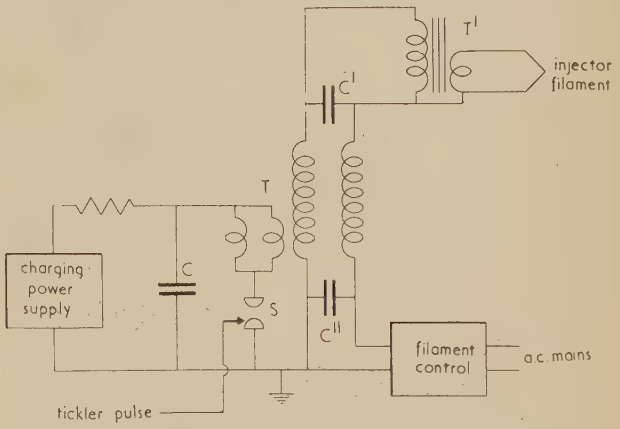

Fig. 2. Schematic diagram of pulse-transformer connexions. In practice, the charging resistor shown is replaced by a vacuum-valve regulating circuit

when used in a suitable insulating medium. Capacitor C, in this case 0·25 μF, is charged to a potential of the order of 20 kV, then discharged through the triggered spark gap S into the primary of the pulse transformer T. (An improved spark gap is described by Hammer and Bureau.$^{(3)}$) The secondary windings of this transformer are split so that low-voltage a.c. may be applied between them to heat the filament. A filament transformer T' is located within the high-voltage terminal so that the large filament currents need not be passed through the pulse transformer windings. Capacitors C', C'' (of the order of 1 μF) effectively connect the two parts of the pulse transformer secondary in parallel for the pulse.

Construction of the pulse transformer is shown in Fig. 3. A brass tube 3 in. in diameter, slotted lengthwise, serves as the winding former and high-voltage terminal. On this are wound the secondaries, each consisting of 200 turns of flat aluminium ribbon 2 in. wide and 0·002 in. thick. Insulation between turns is provided by three layers of cellulose acetate

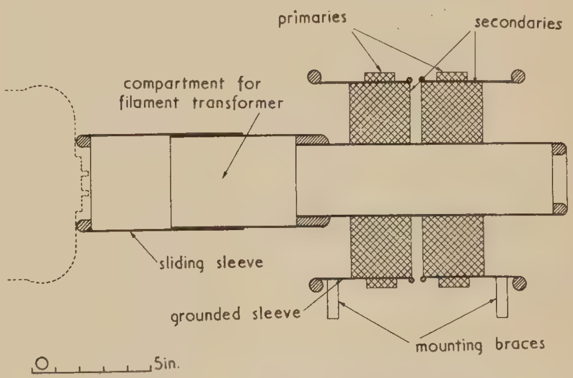

Fig. 3. Section of the pulse transformer. All of the brass tubes used in the construction are slotted lengthwise so as not to act as shorted turns. The sliding sleeve covers the connexions to the accelerating column

sheeting, 0·003 in. thick and slightly wider than the aluminium. A primary winding of four turns of copper 0·015 in. thick and 1 in. wide is wound over each secondary, the two primary windings then being connected in parallel.

In the waveform of the high-voltage pulse one can easily recognize the oscillations of the coupled primary and secondary circuits. The value of C in Fig. 2 is empirically adjusted for maximum peak output voltage. Since this maximum, with the present transformer, occurs on the second half-cycle, the polarity of the charging supply is so chosen as to make the output voltage positive on the first half-cycle; the negative second half-cycle is the one utilized for acceleration of the electrons. The oscillations decay with a value of Q of the order of five when a load current of several amperes is drawn from the secondary. The duration of a half-cycle is about 2 μs. Should a longer pulse be desired, an iron core may be employed in the transformer, and C may be replaced by a lumped-constant delay line.

A pulse transformer similar to the one described was in use with an earlier injector in this laboratory, and no particular difficulties arose over extended periods of use.

(*d*) *Quadrupole lenses.* To provide focusing and adjustment of the shape of the cross-section of the beam to the optimum for synchrotron acceptance, a pair of quadrupole magnets(4) has been constructed. The four rectangular-hyperbolic pole-pieces on each magnet are 2 in. long, 2 in. wide, and have a minimum separation of 1$\frac{3}{4}$ in. Each energizing coil has 1500 turns of No. 25 Brown and Sharpe (26 s.w.g.) insulated copper wire. The field distributions in each magnet were measured with a long rectangular search coil and found to agree closely with those required. To quote typical figures: a field gradient of 75 G/in. is obtained for an energising current of 50 mA through the four coils in series.

PERFORMANCE TESTS

For test purposes, the emergent electron beam, which would in normal service enter the inflector plates of the synchrotron, was deflected by an analysing magnet into a Faraday cup containing a fluorescent screen which could be viewed through a window. The beam current and shape of the beam spot could thus be observed. (A small focusing coil of the type used with cathode-ray tubes is used to counteract the defocusing which takes place when the beam emerges from the accelerating column into a field-free region.) Beam energies were measured by comparison with internal conversion electrons from a ^{137}Cs source.

The dependence of beam current on power supplied to the filament and on energy was measured. Currents recorded were those received through a limiting aperture of 1$\frac{1}{2}$ in. diameter at a distance of 40 in. from the filament (without use of the deflexion or strong-focusing magnets). Representative curves are shown in Figs. 4(*a*) and (*b*). At 450 keV, a maximum beam current of 1 A is obtained for a filament power of 200 W [Fig. 4(*a*)]. A reasonable operating point has been chosen as 150 W, for which the emission is approximately 850 mA.

A strong dependence of emission on voltage is found [Fig. 4(*b*)]. This appears to follow a relation somewhere between a linear law and the three-halves power law of the infinite planar diode, and is probably evidence that the device is only an approximation to the ideal case. (Curves in Fig. 4(*b*) have been normalized at 450 keV.)

The focusing behaviour of the quadrupole lenses has also been verified. Beam shapes such as a horizontal or vertical line or intermediate forms, including a round spot, can be obtained. In normal use the lens currents would be adjus empirically to maximize the circulating synchrotron beam.

On the basis of detailed measurements made in these tes it is anticipated that the current delivered into the sy chrotron doughnut will exceed by a factor of ten the injec beam current at present obtained from a simple two-electro injector. (The Michigan synchrotron being out of order the time of writing, installation of the new injector has be considerably delayed.)

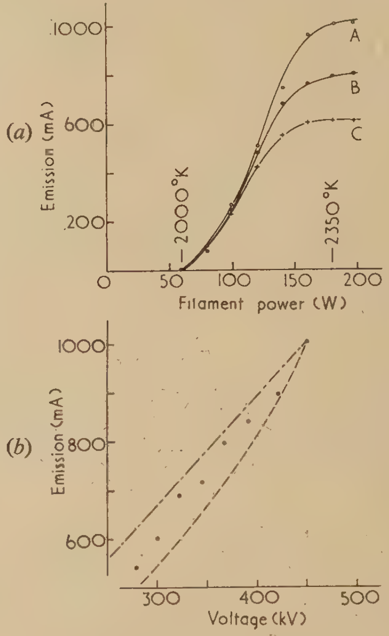

Fig. 4. (*a*) Peak emission current as a function filament heating power

Curve *A*, 450 keV; curve *B*, 365 keV; curve *C*, 300 keV.

(*b*) Peak emission current as a function of energy or voltoge. Curves of linear and three-halves laws are shown for comparison, normalized at 450 keV

— - — - — $I = KV$. — — — $I = K'V^{3/2}$.

ACKNOWLEDGEMENTS

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The authors wish to thank Dr. R. W. Pidd for helpi suggestions and advice, and Mr. O. Haas for construction much of the apparatus. It is believed that the pul transformer design and the use of a water column as volta divider originated with the synchrotron laboratory California Institute of Technology.

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Dielectric measurements on thin films by means of electrodes coated with irradiated silicone rubber

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[*Paper first received* 31 *December*, 1958, *and in final form* 16 *March*, 1959]

The difficulties in measuring the dielectric properties of thin films by conventional methods are discussed and an alternative method of measurement is described. The new method involves the use of electrodes faced with a rubber-like material and it is found that irradiated polydimethylsiloxane is the only material which is entirely satisfactory for the coating of the electrodes. In conclusion, an electrode assembly with which the technique has been proved is described.

a measurement of capacitance on a specimen of ting material, the permittivity may be calculated using uation:

$$c = \frac{\varepsilon A}{4\pi d},$$

c is the capacitance (e.s.u.), ε the permittivity, A the cm^2), d the thickness (cm).

he dimensions of the specimen are such that c is 100 0 pF, then the error in the measurement of capacitance well be less than 0·01%. The errors in the calculation rmittivity, therefore, are primarily the errors in the urement of A and d; of these two factors, d is generally ne which is difficult to measure unless (*a*) the two faces specimen are parallel and smooth, and (*b*) the thickness less than one millimetre.

ny newly developed materials take the form of specimens are far from this ideal and the measurement of permit- presents a real problem. If the surface of the specimen smooth, then errors may be introduced from a number urces. Rigid electrodes lie on the thicker parts of the nen and air pockets are included in the test capacitance. soft, thin, foil electrodes may be bedded on to the nen surface, but the mean thickness cannot be measured eans of a micrometer gauge, even if readings were taken arge number of positions, because of the rigid surfaces e micrometer anvil and spindle. Clearly, under con- ns of badly fitting electrodes, the loss-tangent cannot be ured accurately. Some of the difficulties associated with ectrode contact may be overcome by the series-air-gap od devised by Lynch,(1) but this method still requires smooth specimens.

overcome these difficulties a new technique has been oped. Two sheets of rubber-like material are introduced en the electrodes. A known pressure is applied to the odes, and their separation measured by means of a meter, and the capacitance of the assembly is measured. specimen under test is then introduced between the r sheets and the measurements of separation and itance are repeated under the same applied pressure.

d_1 and d_2, c_1 and c_2 are the initial and final values of ation and capacitance respectively, then the average nen thickness d_s is $(d_2 - d_1)$ and the specimen capaci- c_s is $c_1 c_2/(c_1 - c_2)$. In practice, if a Schering bridge ilar equipment is used for loss measurement, then some fication arises from the fact that the reciprocal of the itance can be read from the bridge arms at balance is, R_3 in the Schering bridge). The equivalent balance R_3^1 for the specimen alone is given by:

$$R_3^1 = R_{3(test)} - R_{3(init.)}$$

$R_{3(test)}$ is the value obtained with the specimen in circuit and $R_{3(init.)}$ is the value obtained on coated electrodes only. Further, it may be shown that the loss-tangent of the specimen, $\tan \delta_{(spec.)}$, is:

$$\tan \delta_{(spec.)} = \frac{R_{3(test)} \cdot \tan \delta_{(test)} - R_{3(init.)} \cdot \tan \delta_{(init.)}}{R_{3(test)} - R_{3(init.)}}$$

As a preliminary test of the technique, measurements were made on a sheet of glass-cloth/polyester board $\frac{1}{16}$ in. thick which had a rough surface because of the coarse weave of the glass cloth. Loss measurements were made on this specimen by three methods: (*a*) the specimen was stressed between aluminium foil electrodes well rubbed on to the specimen surface with a smear of petroleum jelly; (*b*) the specimen was stressed between plane brass electrodes 7 in. and 6 in. diameter, the latter having a guard ring $\frac{1}{2}$ in. wide; (*c*) the specimen was stressed between the brass electrodes of (*b*) covered with a layer of natural soft rubber, $\frac{1}{16}$ in. thick.

Table. 1. *Dielectric loss measurements on a polyester/glass-cloth bonded board*

(All measurements in air at 20° C and a frequency of 50 c/s.)

Type of electrodes	ε	*tan δ*
Greased foils 7 in. diam. electrode plus 6 in. diam. with $\frac{1}{2}$ in. guard ring	4·6	0·027
Plane brass 7 in. diam. electrode plus 6 in. diam. with $\frac{1}{2}$ in. guard ring	4·5	0·069
Plane brass as above plus 2 sheets of soft rubber ($\frac{1}{8}$ in. thick total)	4·6	0·055
Natural rubber only	2·8	0·008

The results of these measurements are shown in Table 1, from which it is clear that, as a general-purpose technique, natural soft rubber has too high a loss-tangent. An alternative rubber-like coating was therefore sought which had a negligible loss-tangent. In addition to this requirement, it would be an advantage if the coating were heat- and solvent-resistant, so that the electrodes could be used under varying conditions (at high temperatures or in an oil bath, for example), and it would also be an advantage if the coating—while having appreciable adhesion to the metal of the electrode—had a non-stick surface, so that a sample film could readily be removed from the electrodes after compression between them.

DEVELOPMENT OF A "LOW-LOSS" RUBBER-LIKE COATING MATERIAL

Conventional rubbers have too high a dielectric loss, probably because the curing agents or catalysts employed in their manufacture (sulphur compounds or peroxide compounds, for example), invariably leave polar groups or residues in the rubber. Curing of many of these materials can be achieved by exposure to high energy radiation, and this method may produce an improved product because no catalyst is employed in the curing process; natural rubber, neoprene and certain other synthetic materials can be cured by this means to give a resilient rubber. However, many of these improved products were again unsuitable because of an inherent dielectric loss in the uncured state and also a susceptibility to oxidation at elevated temperatures.

Theoretically, irradiation-cured silicone rubber should have none of these disadvantages. The pure base material, polydimethylsiloxane, has an extremely low dielectric loss at frequencies of up to 10^8 c/s⁽²⁾ (Fig. 1) and is resistant to oxidation at high temperatures. The dielectric properties of various silica-filled, catalyst-free silicone rubbers were therefore examined after curing by irradiation. The samples were in the form of $\frac{1}{16}$–$\frac{1}{8}$ in. thick sheet which had been cold-pressed from the gum-filler mix between glazed paper and then irradiated in air in stacks up to $\frac{1}{2}$ in. in thickness with electrons from a 4 MeV Orthotron.⁽³⁾ The dose rate was, for experimental convenience, 1 Mrad min^{-1}. At this dose rate, the small quantity of gaseous decomposition products produced during the irradiation crosslinking process readily diffused out of the polymer. Furthermore, because little heat is involved in the irradiation process (of the order of 2 cal g^{-1} Mrad^{-1} only) there was no risk of bubbling or void formation.

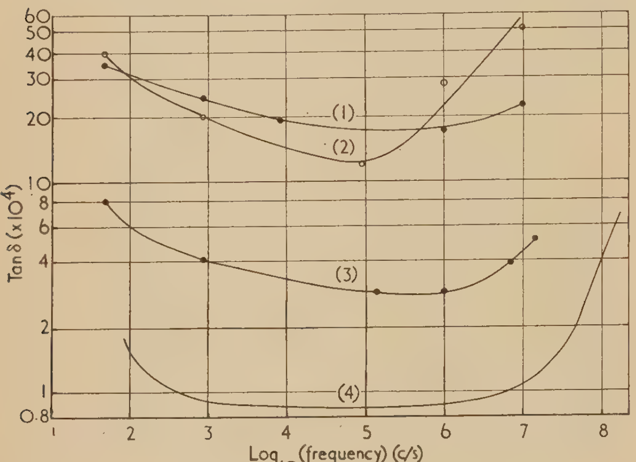

Fig. 1. Variation of loss-tangent with frequency

(1) Peroxide-cured, silica-filled; (2) irradiation-cured, silica-filled; (3) irradiation-cured, silicone gum (type K. 9111, by Midland Silicones Ltd.) dusted with talc; (4) silicone liquid.⁽²⁾

Dielectric measurements were made on these irradiated rubbers at 50 and 800 c/s by means of a Schering bridge. At higher frequencies (10^5–10^7 c/s), the Hartshorn and Ward resonance method was used.

It was at first surprising that irradiation curing did not appear to produce a markedly improved product compared with the conventional chemical curing (see Fig. 1, Curves 1 and 2). This was, however, eventually attributed to polar impurities such as adsorbed moisture entrapped in the silica filler. Irradiation-curing is completed in a few minutes and involves little heating of the sample. Consequently, far more of these volatile impurities will be entrapped than in the conventional curing process where the material is maintained at 200° C or more for a considerable time.
improvement resulting from the absence of catalyst resi
was therefore probably masked by the impurities prese
the silica filler. This explanation is supported by the obse
tion that the dielectric loss of the irradiation-cured rub
was reduced markedly with increased irradiation (see Fig
This improvement results undoubtedly from the respons
the polar impurities becoming progressively restricted
additional crosslinking.

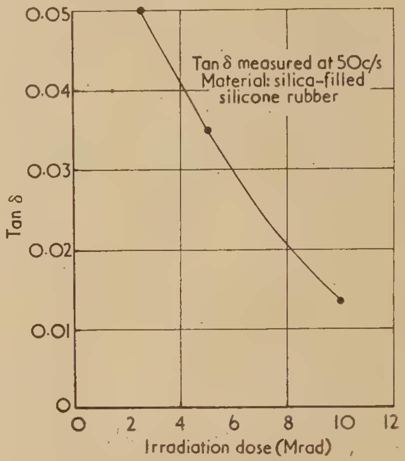

Fig. 2. Variation of loss-tangent with irradiation dos

By the omission of the silica filler and by simple irradia
of a pure polydimethylsiloxane (supplied by Midland Silic
Ltd.), a cured silicone rubber was obtained with diele
properties approaching that of the original polymer.
careful selection of the irradiation dose, this "low-
rubber was produced with optimum tensile properties wh
though poor when compared with silica-filled rubbers,
adequate for a thin film supported by a metal backgrou
The absence of filler had the added advantage that
material possessed a low value of Young's modulus and
therefore well suited to compensate for surface irregularit
The rubber was also found to have adequate adhesion
metal surface when vulcanized *in situ*, and a smear of silic
oil, type M.S. 200 (by Midland Silicones Ltd.), or a
dusting with a fine talc powder gave the exposed surface
required non-stick characteristic. The optimum dose
curing this material was found to be 5 Mrad. At this d
it can be seen from the solubility/dose curve (Fig. 3) that
silicone was, to a large extent, insoluble.

The excellent resistance to oxidation of polydimet
siloxane was evident during the irradiation of this silic

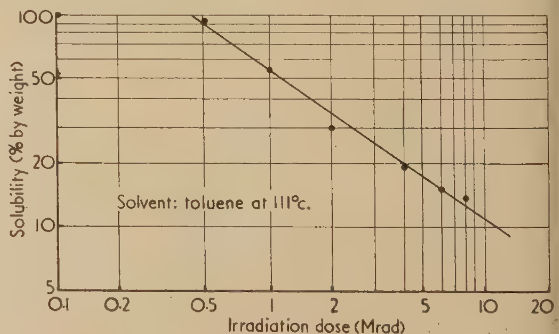

Fig. 3. Solubility of polydimethylsiloxane as a functio
of irradiation dose

s found that no precautions were required to prevent ce oxidation of the material during irradiation. This is rked contrast to organic polymers which—especially in orm of a thin film—oxidize rapidly on irradiation ise of the production of ozone and atomic oxygen in urrounding atmosphere and large quantities of free als in the polymer. This ultimately gives rise to carbonyl other polar groups on the surface of such polymer films.

e pure dimethylsiloxane polymer of high molecular it finally used to coat the electrodes was originally in orm of an extremely viscous water-white liquid. A thin in.) uniform film of this polymer was conveniently sited on small (1 in. diameter) electrodes in the following ier. A weighed pellet of the gum—in generous excess e calculated quantity required to cover the electrode ce to the desired depth—was placed at the centre of the ically cleaned electrode surface. The electrode was then ited in a centrifuge in such a manner that, on rotation e centrifuge head, the electrode face to be coated faced xis of the centrifuge and the silicone gum became evenly rsed over the electrode surface by the centrifugal force. centrifuging was continued until the required film thick- was obtained.

rger electrodes were not suited to the above treatment. ad, a weighed pellet of the silicone gum at the centre of lectrode was covered by a nylon film followed by a glass plate and a pressure of the order of 100 lb in.$^{-2}$ ipplied in a spring-loaded press. After the silicone had observed to disperse over the full surface of the electrode, ressure was released and the thickness of the film was l from the change in micrometer readings between the i film and the back surface of the electrode. When the red film thickness was obtained, the nylon film was ully peeled away. Then, until the electrode could be iated, it was mounted horizontally to prevent the silicone flowing unevenly.

e silicone film (*in situ* on the electrode) was converted the cured rubber by irradiating to the optimum dose of ad at a dose rate of 1 Mrad min^{-1}. At this dose rate, s found that the electrodes could be mounted vertically ont of the electron beam with no risk of the silicone film rting during irradiation. It can be seen from Fig. 3 even after only 1 Mrad, a considerable proportion of ilicone is gelled (that is, is insoluble in boiling toluene) herefore will not flow as a liquid.

THE COMPLETE EQUIPMENT

veral methods of mounting and applying a prescribed ure to the irradiated silicone-faced electrodes were tried, he method finally adopted is shown in Fig. 4. The pair ectrodes (*a*) (1½ in. diameter with a ¼ in. radial guard were carried on, but insulated from, a hinged steel e (*b*), the spindle (*c*) of the hinge being extended and iined to a cone at each end. These two cones are located nical bearings (*d*) so that the frame assembly can swing v. The centre of the electrodes is 6 in. below the fulcrum a total compressive force of about 10 lb is applied by tension springs (*e*) mounted in line with the centre of lectrodes. Two steel balls (*f*) are fitted to the frame below the fulcrum and the base of the assembly has a cal spigot (*g*) on which a bench micrometer fits, the lle and anvil of which engage with the steel balls. This igement yields a magnification of 4/3 of the specimen ness. To enable the bench micrometer to be removed, ertical members (*h*) which carry the assembly are pivoted near the base (*i*) and a supporting arc-shaped member (*j*) passes through a slot in one vertical member which, in turn, is fitted with a set screw (*k*).

A series of 100 measurements of the electrode separation with and without a specimen 0·008 in. thick between the electrodes showed that the standard deviation of the thickness measurements was 0·0001 in. To evaluate the accuracy of this electrode system, it was essential that dielectric measurements were carried out on films which could be checked by conventional means. These were consequently smooth films. A measurement of the permittivity of a film of cellulose triacetate was made (*a*) between graphite electrodes painted on to the specimen surface and backed with aluminium foil, and (*b*) between the silicone-coated electrodes. Finally, a measurement was made on a smooth mica specimen between (*a*) foil electrodes without a guard ring, and (*b*) silicone-coated electrodes. The results are given in Table 2.

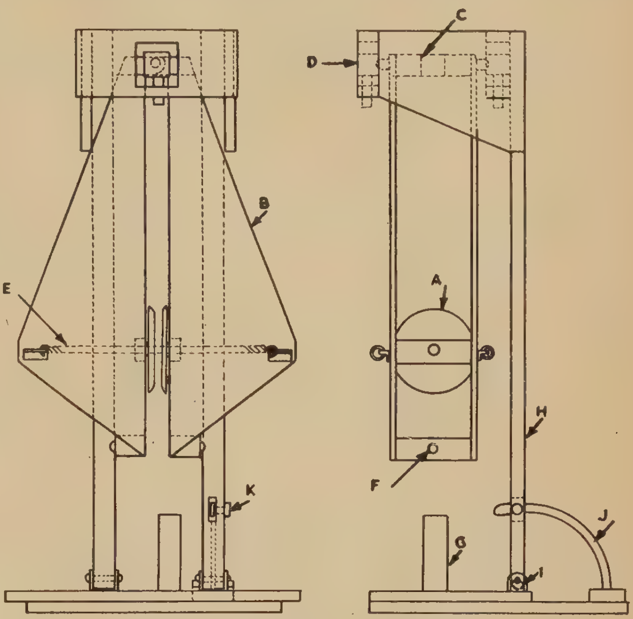

Fig. 4. Electrode assembly

Table 2. *Comparison of conventional methods and the new technique using irradiated silicone-coated electrodes*

(All measurements in air at 20° C and at a frequency of 50 c/s)

Specimen	*Electrodes*	ε	*tan δ*
Cellulose triacetate (0·008 in. thick)	graphite	4·11	0·011
Cellulose triacetate (0·008 in. thick)	silicone-faced	4·07	0·011
Mica (0·0023 in. thick)	foil	6·2	0·0024
Mica (0·0023 in. thick)	silicone-faced	6·4	0·0023
Silicone-faced electrodes only		—	0·0008

The imperfections which can be accommodated between these electrodes are surface ripples or indentations of 0·001 or 0·002 in. deep. Clearly, surface irregularities having a depth of the order of the thickness of the electrode coating cannot be accommodated. Furthermore, specimens having a surface irregularity consisting of a single plateau, or similarly shaped indentation covering most of the electrode area, may not be measured accurately, but, in practice, it has been found that such local changes in thickness of the order of 0·001 in. introduce inaccuracies in the measurement of the mean thickness which are smaller than those of the micrometer.

CONCLUSIONS

A new technique has been developed which enables loss measurements to be made on imperfectly shaped specimens of insulating material which otherwise could not satisfactorily be tested. The technique places onerous requirements on the material with which the electrodes are faced, but a newly developed irradiation crosslinked polydimethylsiloxane has been found to meet these requirements.

ACKNOWLEDGEMENT

The authors wish to thank Sir Willis Jackson, Direct of Research and Education, for permission to publish t paper.

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Inductance bridge for sensitive displacement measurements over long periods*

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This paper describes an application of linear differential transformers in an a.c. bridge that provides reproducible displacement measurements over long periods, extends the linear response whilst retaining high sensitivity, and can be readily adapted for automatic recording of displacement.

Deformations are produced in stressed specimens during the use and testing of engineering materials that require the measurement of a wide range of strains to various degrees of precision. In a specific application, for example, high-sensitivity creep testing, the total plastic strain to be measured may only be 0·1% during a period of 10 000 hours or longer. Other forms of testing require the measurement of larger plastic strains in periods from a few minutes upwards. In large structures, displacements of thousandths of an inch have to be measured after periods of many years.

Where large numbers of test units are operated using the method described, labour can be saved in analysis as the strain or displacement data is read in a form suitable for immediate entry into permanent records. Electrical methods permit the remote control of strain measurement in those classes of testing where the unit is inaccessible during a test, for example, measurements under radio-active conditions or in the interior of large civil-engineering structures.

The transducer system described will translate a mechanical movement (of a creep extensometer, for example), into an electrical output indicating strain. It is a mutual-inductance bridge, applicable to both metal and air-core linear differential transformers,(1, 2, 3) and is stable over long periods of operation. It extends the range of measurement for these transducers while retaining high sensitivity, and can be adapted to provide an automatic recording system.

Details for connecting the transducers to a particular moving system, such as extensometer limbs, are not discussed except to emphasize that in any application the transducers should reproduce the mechanical movements with a degree of accuracy sufficient to achieve the required overall accuracy of measurement. Examples are shown in Fig. 1 of typical transducers mounted on N.P.L. creep extensometers.

LINEAR DIFFERENTIAL TRANSFORMERS FOR DISPLACEMENT MEASUREMENTS

Metal-core types. The metal-core linear-differential transformer consists of a cylindrical core, made from a suitable transformer material, that move along the axis of th coaxial coils which form a transformer with two identic secondary windings situated on either side of a prim winding. Schævitz(1) energized the primary winding wi alternating current, and connected the secondaries in se opposition and thence to an amplifier and indicator syst which measured the difference signal from the second windings. With the core in various positions along the ax of the transformer, voltages are induced in the second circuit that are related to the core position and have a shaped characteristic with two linear portions. As a dir reading instrument, it depended upon electronic amplificati and high stability over long periods was difficult to achi with simple apparatus. The sensitivity of measurement w such transducers could be better than 10^{-5} in., as w reported by Leeman and Grobbelaar.(4) Schævitz also pr posed a circuit, having better stability over long perio which used two identical transducers with opposing outpu that were compared by a null-balance indicator. Howev the sensitivity with which the motion of one transducer w measured was limited by the accuracy with which the motio of the balancing transducer was produced and measured.

The mutual-inductance bridge described here (and al recently by Heath(5)) includes a linear-differential transform similar in form to that used by Schævitz, but in which t secondary windings are not interconnected. The tw secondary windings of the transformer are used as arms the bridge (Fig. 2), which is balanced by non-inducti resistances in the other arms. Thus the displacements of core of the transformer, which is linearly related to t mutual inductances between the primary and second windings, can be measured in terms of resistances in t bridge. The balance of the bridge is detected with a pha sensitive null-balance indicator and the stability of measu ment will not depend upon an electronic amplifier. T sensitivity in detecting the balance condition for the brid will depend upon the indicator, and is also proportional the square of the a.c. frequency used.

When the bridge is balanced, there is a linear relationsh between the values of the balancing resistances and t on of the core, if the a.c. frequency is low and the s of the balancing resistances ($R_3 + R_4$) is relatively (see Appendix). The shape of the response curve, n in Fig. 3, indicates a linear region twice that obtained Schævitz application of differential transformers. The t of the linear region will depend upon the dimensions core and windings in a particular transformer.

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* Brit. Pat. Appl. No. 20 641/58.

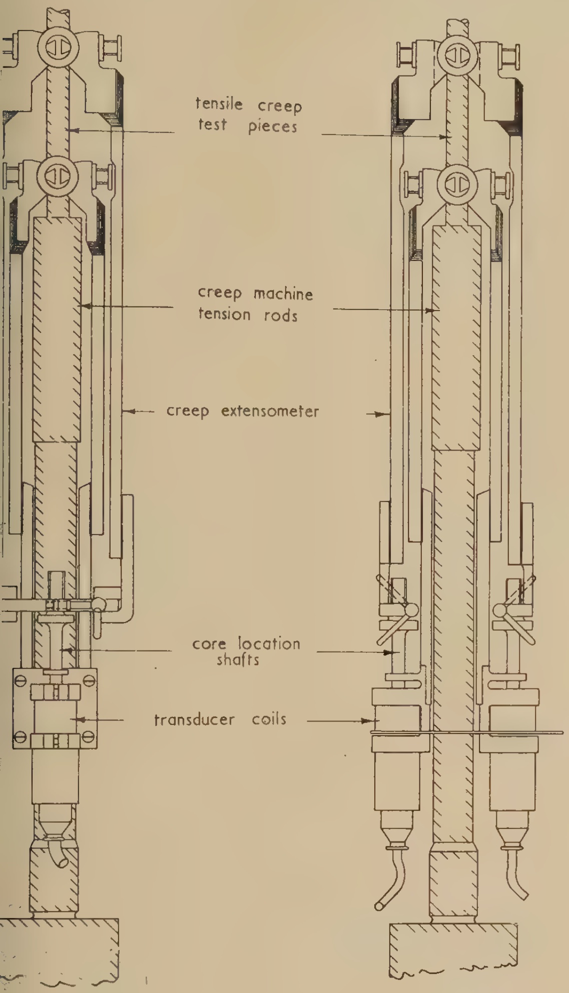

Fig. 1. Transducers fitted to creep extensometers

-core types. In certain applications, air-core linear-ential transformer systems are preferable. In such ments (as developed by C.N.S. Instruments Ltd.,(3) for ole) the primary windings are energized with 8 kc/s ating current and the secondary windings are connected ies-opposition to an amplifier and indicator to form a -reading system. The air-core differential transformers so be used in a mutual-inductance bridge with a circuit r to that used for the metal-core transducers to provide thod of displacement measurement which does not d upon the long-term stability of an electronic amplifier. ensitivity for detecting the bridge balance condition is rtional to the a.c. frequency; while the linearity of the nse curve is only dependent upon the dimensions of the ngs on the transformers.

formance of new transducer system. A practical ring system will be a compromise between the relative tages of the metal-core and air-core linear-differential transformers. This compromise will be influenced by the conditions in which the system is used; an air-core transducer, for example, will be used where it is undesirable to have ferritic material present.

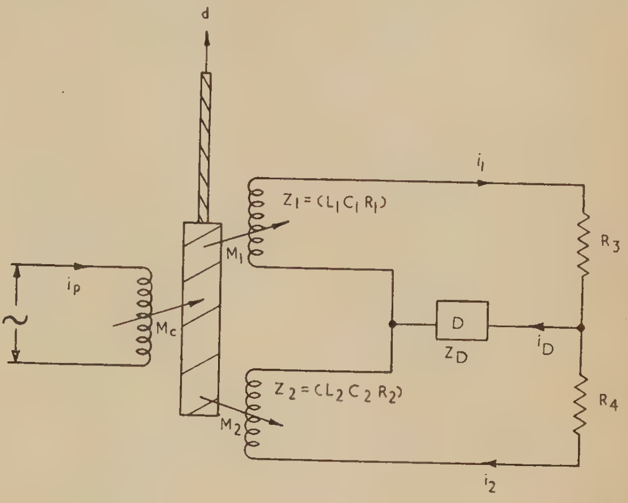

Fig. 2. Bridge circuit for transducer

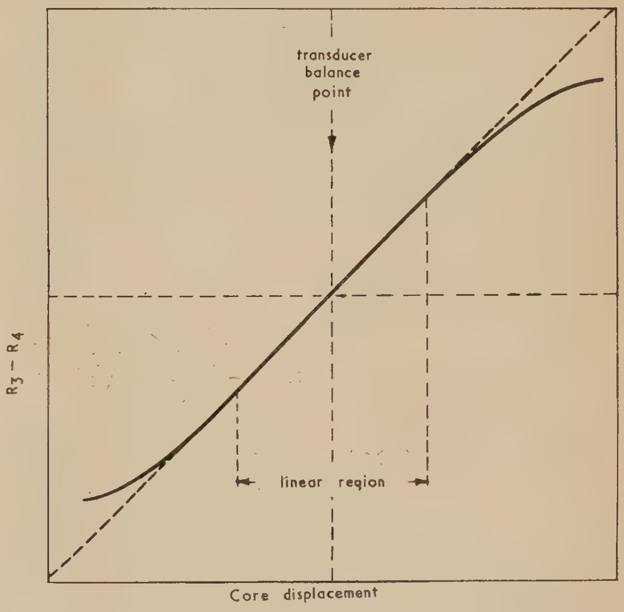

Fig. 3. Response curve for metal-core transducer in bridge circuit

In the present application, metal-core transducers were used in the bridge energized with 50 c/s current, which eliminated the need for a separate oscillator and fulfils one of the conditions for improving the linear response of the system. The bridge balance condition was detected with a simple phase-sensitive indicator which was adequate because the sensitivity of measurement is proportional to the square of the a.c. frequency. The effects of spurious signals, resulting from inductive and capacitive pick-up from the mains supplies to other laboratory equipment, were reduced to negligible levels by careful layout of circuits and adequate screening of leads. An advantage of operating the bridge at a frequency of 50 c/s is the possibility of using the "out-of-balance" signal from the bridge to energize, after amplification, a normal servo-motor to drive a self-balancing and recording potentiometer which forms the basis of an automatic recorder (Fig. 4). Alternatively, the servo-motor can actuate any other mechanism (for positional control of machine tools, for example) from movements detected by the transducer.

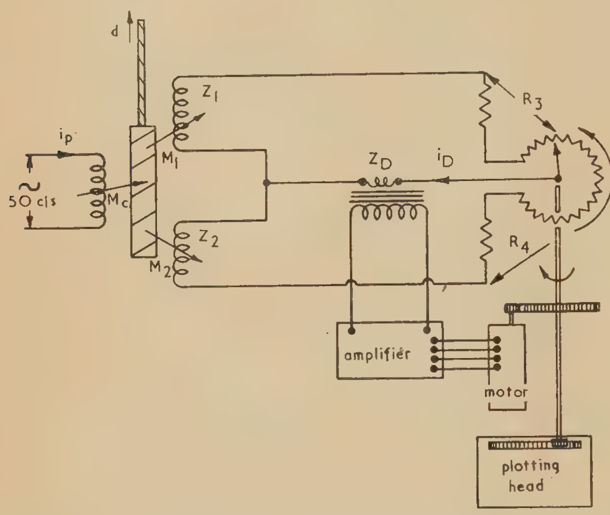

Fig. 4. Transducer bridge balanced automatically and linked to plotting head of recorder

To investigate the suitability of this bridge method for measuring displacements, the connexions of one type of metal-core transducer (the displacement transducer, type F11, by Boulton Paul Aircraft Ltd.), chosen from the m which are commercially available, were modified for us this system. In a typical bridge, the sensitivity of meas ment was shown to be 4×10^{-6} in. when an interferome method was used to measure the movements applied to transducer. This system had a range of 0·050 in. near middle of the response curve in which the calibration devia from linearity by $2 \cdot 5 \times 10^{-5}$ in. and a range of 0·10 in which the calibration was linear to within 1%. There an overall useful range of 0·20 in., but at the ends of range the calibration deviated 5% from linearity.

To provide parameters for bridge design using the transducer, curves were plotted (Fig. 5) which show relationship between displacement, equivalent to a spec change in the balancing resistances $(R_3 - R_4)$, and values the sum of the balancing resistances $(R_3 + R_4)$. The cur have an accuracy of $\pm 1 \times 10^{-4}$ in. These curves provide the value for the balancing resistances $(R_3 +$ that will make a specific change of the balancing resistan $(R_3 - R_4)$ numerically equal to a specific displacement, t facilitating the provision of a direct-reading decimal scale measurements.

Application of the method to creep testing. This mut inductance bridge was applied to strain measurements du creep tests on materials at elevated temperatures. Some transducers were modified and fitted to a number of N. high-temperature creep extensometers (Fig. 1). Bri conditions were chosen, using the design curves in Fig so that a minimum change of resistance $(R_3 - R_4 =$ was equivalent to specific strains in particular-sized pieces, and a decimal scale was provided for reading str Two sensitivity ranges were provided.

Strain measurements during creep tests

Testpiece gauge length (in.)	*Minimum strain measurement (equivalent to 1 Ω) (in.)* (a)	(b)	*Total strain mea by F11 transdu (%)*
5	1×10^{-5}	1×10^{-4}	4
2	1×10^{-5}	1×10^{-4}	10
1	2×10^{-5}	1×10^{-4}	20

A number of creep tests has been performed using exten meters fitted with a single F11 transducer which lasted fr 50 to over 1000 h. The scatter in the measurements similar to that obtained from conventional creep exten meters which are fitted with "rhomb and mirror" opti levers. The results are shown in Fig. 6.

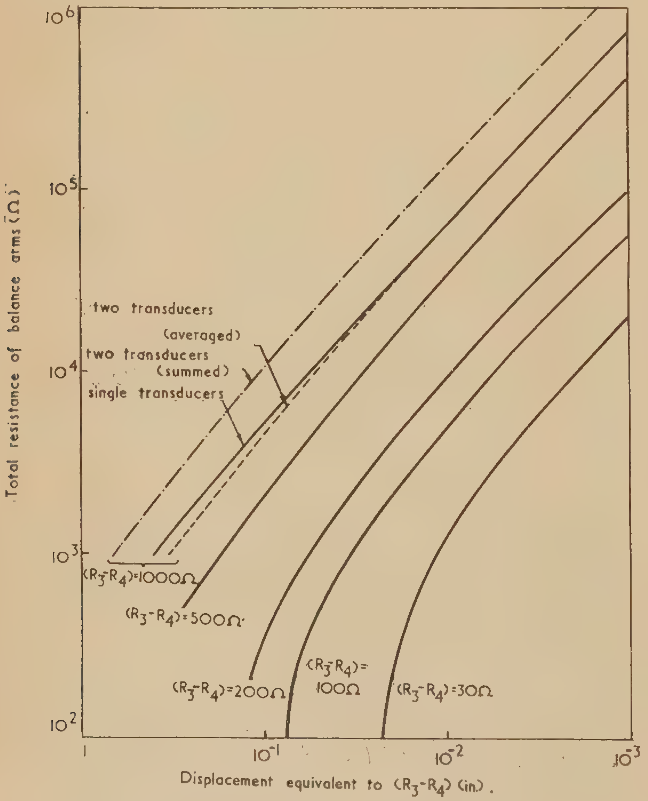

Fig. 5. Design curves for F11 transducers

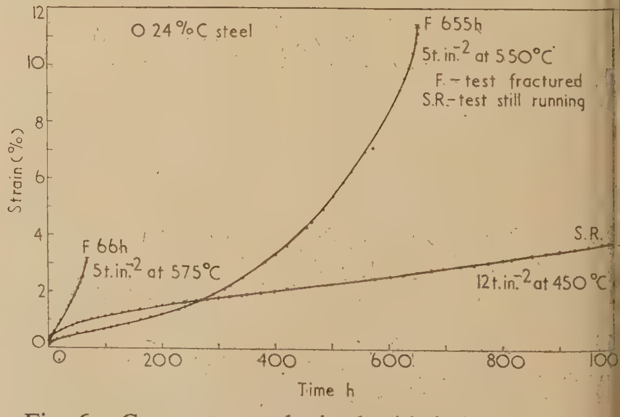

Fig. 6. Creep curves obtained with inductance-bridge strain recorder

CONCLUSION

bridge using the metal-core linear-differential trans- r is simple, and its long-term stability depends on the ty of the physical dimensions of the transducer, the ty of the values of the balancing resistors and changes ntact resistance of switches or potentiometers used, than on the reproducibility of an electronic amplifier. ecessary use of a low-frequency alternating current to ze the bridge gives better linear response, permits the operation of normal servo-motors and facilitates the of recording or control systems.

ACKNOWLEDGEMENTS

author wishes to acknowledge the permission from irectors of N.P.L. and M.E.R.L. to present this paper, couragement of Dr. N. P. Allen to develop this method reep-strain measurements, and to members of the 1.P. section at N.P.L. for the discussion and assistance essing the suitability of this method.

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PPENDIX—THEORY OF BRIDGE CIRCUITS

Symbols

i_p = current in primary winding
nd i_2 = currents in secondary windings
ω = pulsitance of alternating current in primary winding
M_c = mutual inductance between primary winding and metal core
d M_2 = mutual inductance between metal core and secondary windings
$= M_1 = M_2$ at the mid position of the metal core with respect to windings)
V = induced e.m.f. in each secondary with the metal core in the mid position with respect to the secondary winding
ΔV = change of induced e.m.f. in secondary windings after core (or primary winding) is moved from the mid position
Z_c = impedance of metal core
Z_D = impedance of indicator
d Z_2 = impedance of secondary winding, that is, $Z_1 = Z(R_1, L_1, C_1)$
$= L_1 = L_2$ at the mid position of metal core)
d R_4 = non-inductive resistances in the balancing arms of bridge

Metal-core transducers. From the circuit given in Fig. 2, the voltages induced in secondary windings when the core is displaced from the mid position are:

$$V + \Delta V = i_p\omega^2 M_c M_1/Z_c = i_1(Z_1 + R_3) + i_D Z_D; \quad (1)$$

$$V - \Delta V = i_p\omega^2 M_c M_2/Z_c = i_2(Z_2 + R_4) - i_D Z_D. \quad (2)$$

from which $\Delta V = i_p\omega^2 M_c(M_1 - M_2)/2 \,.\, Z_c$,

and $V = i_p\omega^2 M_c M/Z_c$

Also from Fig. 2,

$$i_1 = i_D + i_2,$$

and

$$\begin{aligned} V(Z_2 + R_4 - Z_1 - R_3) &+ \Delta V(Z_2 + R_4 + Z_1 + R_3) \\ &= i_D\{(Z_2 + R_4)(Z_D + Z_1 + R_3) + Z_D(Z_1 + R_3)\}. \quad (3) \end{aligned}$$

Thus

$$\begin{aligned} i_D = i_p\omega^2 M_c\{2M(Z_2 + R_4 - Z_1 - R_2) &+ \\ &+ (M_1 - M_2)Z'\}/2ZZ_c, \quad (4) \end{aligned}$$

where $Z = (Z_2 + R_4)(Z_D + Z_1 + R_3) + Z_D(Z_1 + R_3)$,

and $Z' = R_3 + R_4 + Z_1 + Z_2$.

In the balance condition $i_D = 0$. Therefore

$$(M_1 - M_2)/2M = \{(R_3 - R_4) + (Z_1 - Z_2)\}/Z'$$

Within the region of linear response of the transducer, changes in mutual inductance and self inductance of the secondary windings are proportional to the displacement of the core, and the balance condition can thus be re-written:

$$\begin{aligned} \Delta M/M - 2j\omega\Delta L/Z' = \{(R_3 - R_4) + (R_1 - R_2)\}/Z' &+ \\ + j(1/C_1 - 1/C_2)/\omega Z'&, \end{aligned}$$

where $\Delta M = M - M_1 = M_2 - M$,

and $\Delta L = L - L_1 = L_2 - L$.

For a well-designed transducer system, $R_1 = R_2$ and $C_1 = C_2$ and, if $(R_3 + R_4)$ is constant,

$$(R_3 - R_4)/Z' = \Delta M/M - 2j\omega\Delta L/Z' \quad (5)$$

Thus, if the term $2j\omega\Delta L/Z'$ is made very small, $(R_3 - R_4)$ is proportional to ΔM, and $(R_3 - R_4)$ is proportional to the displacement d of the core.

This relationship is shown in the response curve in Fig. 3. The extent of the linear region will depend on the dimensions of the metal core and the windings of the transformer, and on the magnitude of the reactive term in equation (5). A consequence of this term is a residual signal in the balance condition for the bridge, having the same frequency as the current supplied and odd harmonics of this frequency. This signal is proportional to the supply frequency and the displacement of the metal core from the mid position; it is also inversely proportional to Z'. Thus, if the a.c. frequency is low and the value of Z' is relatively large, then the linearity of the response curve can be maintained over a useful range. The magnitude of the out-of-balance signal i_D will be proportional to the square of the supply frequency.

This analysis may be extended to include the summation of several displacements detected by a number of transducers connected into the bridge.

Relative energy calibration of electron accelerators

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[*Paper received* 19 *January*, 1959]

Measurements of electron transmission through metallic foils suggest that accurate relative calibration of an electron accelerator may be possible using foil transmission data. Standardization of measurement at a predetermined very small transmission ratio for a series of beryllium-foil thicknesses would lead to calibration data nearly independent of apparatus. A circuit for the measurement of electron-beam current ratios is described. This circuit is particularly suited to the measurement of the very small transmissions recommended.

Energy calibration of an electron accelerator of about 1 meV maximum energy is generally an elaborate or inaccurate procedure. For example, the procedure in this laboratory for experiments with a 1 MeV electrostatic electron accelerator(1) has been to calibrate a generating voltmeter against a spark gap up to 212 kV and against a resistance column up to 290 kV. This calibration is extrapolated for operation at higher energies, so that the inaccuracies of spark-gap measurements then become more serious.

A satisfactory, non-absolute, calibration procedure should, (*a*) be simple, (*b*) operate on the electron beam directly, and (*c*) be independent of the particular apparatus employed. If aspect (*c*) can be achieved practically, comparison between laboratories can be made and, in particular, a comparison can be made with a generator which has been calibrated absolutely.

ELECTRON TRANSMISSION THROUGH FOILS

A series of measurements of the transmission through metallic foils of electrons in the energy range 0·25–0·75 MeV, has been made recently in this laboratory(2,3) with beam currents of the order 5 μA. These measurements show that transmission may be a very sensitive function of beam energy, and also that the dependence of transmission on collector geometry can be made very small. In view of the three requirements stated above it is suggested that transmission measurements could be arranged as a sensitive method for electron-accelerator energy calibration.

It is desirable to employ as low a transmission as can be conveniently measured. Clearly, the energy at which electrons just fail to emerge from the foil is independent of the collector geometry and depends only upon the foil material and thickness. This quantity can be controlled with accuracy. Because of the straggling in energy loss and the large-angle scatterings that occur during electron penetration in a foil, a true cut-off energy cannot be defined. The incident beam energy resulting in a particular transmission is, however, precisely defined. The increase in transmission with energy above the cut-off region is more rapid the lower the foil atomic number. Beryllium is therefore most suitable for this application.

MEASUREMENT OF CURRENT RATIO

A convenient method for the direct measurement of the ratio of two currents—in this case the transmitted current i_1 and the absorbed and reflected current i_2—is shown in Fig. 1(*a*).

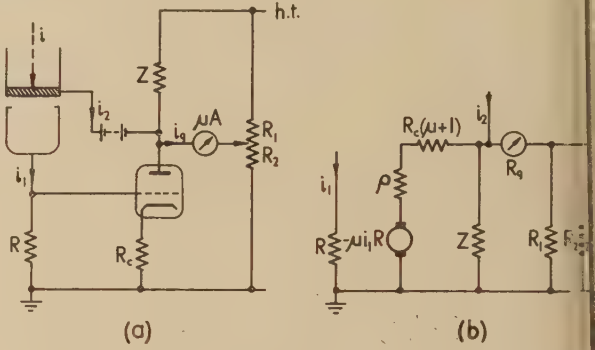
The circuit is a bridge network with negative feedback from the cathode resistance R_c. The circuit is first balanced ($i_g = 0$) by means of the potentiometer R_1R_2 before the beam current flows. The current absorbed and reflected by the foil then flows into the anode circuit, while the transmitted current flows through the grid resistance R. These curr must flow from practically infinite impedances, as in present application. The equivalent circuit for linear va operating conditions is shown in Fig. 1(*b*). It can be that balance is restored provided

$$i_2[R_c(\mu + 1) + \rho] = i_1\mu R$$

that is,

$$t = \frac{i_1}{i_2} \doteq \frac{R_c + R_c/\mu + 1/g_m}{R} \doteq \frac{R_c^1}{R}$$

For most valves, $\mu \gg 1$. Therefore, if R_c is large compa with $1/g_m$, the balance condition becomes insensitive to s changes in valve performance. The balance is indepen of the value of $(i_1 + i_2)$.



(*a*) (*b*)

Circuits (*a*), bridge network; (*b*) equivalent circuit

Although this circuit may be used to measure any curr ratio, it is particularly suitable for the measurement of v small current ratios. This may be seen by determining out-of-balance current i_g for a given change in current rati under the condition that $(i_1 + i_2) = i$ remains consta Thus at balance

$$\frac{di_g}{dt} = \frac{i}{t(t+1)},$$

assuming R_g, R_1, $R_2 \ll Z$. If a very small current ratio employed, a high sensitivity is therefore obtained. This also the most suitable condition for energy calibration, pointed out previously.

PRACTICAL APPLICATION

In a practical application the values of R and R_c determined, to some extent, by the valve employed. electrometer valve is particularly suitable because a la value of R_c can be used while still obtaining correct catho bias and, of course, a very large value for the grid resista R can be used. To demonstrate this method, an electrome valve type ME1400 (by Mullard Ltd.) was used with cathode resistance R_c of 20·9 kΩ and an anode current ʟ.: At this operating point, $1/g_m$ is 3·3 kΩ and μ is rresponding to a value for R_c^1 of 25·2 kΩ. A beam t of several microamperes was directed on to a ım foil (thickness 163 mg cm^{-2}) in the foil clamp and or cup assembly previously described.(2) In order to ss low-energy secondary emission from the foil, an nal 100 V positive bias was applied by inserting a in the foil lead. The electron-beam energy was until balance was restored. With R equal to 10·1 MΩ, onding to a current ratio t of 2·50 × 10^{-3}, a balance und at electron energy 410 keV. This balance energy und to be independent of beam current over the range ed, 1–14 μA. At 4 μA, the energy sensitivity of the at balance was found to be about 0·4 μA per keV, represents a very rapid transition through the balance on.

low transmission value employed in this demonstration be a suitable operating point at which to obtain tion data with an absolutely calibrated accelerator. ll error in the value of R_c^1/R would not seriously affect lance energy, because the operation is close to the region. This latter point is demonstrated in the table shows how the balance energy E varied as R was over the range 1–20 MΩ.

Variation of balance energy with grid resistance

Grid resistance, *R* (MΩ)	1	3·3	5	10	20
Balance energy, *E* (keV)	424	420	415	410	394

It is seen that for a resistance R of 10 MΩ, an error of 10% in the value of t would change the balance energy by less than 0·5%.

Finally, it may be pointed out that the circuit given above may find application in other problems involving the measurement of electron-beam current ratios. A current ratio as small as about 10^{-5} could be measured with this simple circuit.

ACKNOWLEDGEMENT

The authors wish to thank Dr. W. E. Spear for helpful discussions.

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7 kW plasma jet for laboratory use

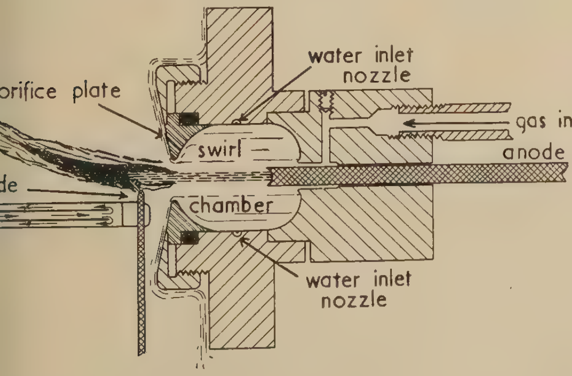
By A. B. Osborn, B.Sc., Royal Aircraft Establishment, Farnborough, Hants.

[*Paper received* 6 *March*, 1959]

The usual form of cathode for plasma jet apparatus is a graphite disk having a central hole through which the jet of plasma emerges. Burning of the graphite continuously enlarges the hole and necessitates frequent renewal of the disk. For small-scale work, this inconvenience can be avoided by replacing the disk with a metal orifice plate (electrically neutral), and by using an external graphite rod as cathode. With the 7 kW apparatus described, the jet of plasma produced is some 5 cm long, with a maximum core temperature believed to be about 10 000° C. The maximum rate of heat transfer to a surface of 6 mm diameter is approximately 300 cal cm^{-2} s^{-1}. By injecting various gases the atmosphere of the arc can be modified. Argon is notable for reducing the arc voltage by about 30%, and for suppressing the usual crater formation at the anode.

INTRODUCTION

water constricted carbon arc has received considerable ty in American journals as a source of high temres. Illustrations usually show apparatus based on the l design published by R. Weiss.(1) For small scale nental work, apparatus has been developed with a nt arrangement of cathode. This is more convenient permits steadier running of the arc, and could easily pted to allow continuous operation.



7 kW plasma jet apparatus

The construction of the apparatus is shown in the figure. Water flows through tangential nozzles into the swirl chamber, where it spins rapidly about the horizontal axis. Under the influence of centrifugal force a cylindrical vortex or air space is formed along the axis. This space is used to contain the discharge of a carbon arc. Intense cooling by the water surface prevents adjacent gas layers from becoming electrically conductive. The main arc current is thus confined to a rather narrow core along the axis of the vortex. At high current, the concentration of energy in the central core of the discharge results in a very high plasma temperature. The construction of the apparatus is described below, and some observations on the behaviour of the arc and the effects of the arc atmosphere are mentioned.

DESIGN OF ARC

Instead of the disk cathode employed by Weiss, a graphite rod is used. It is mounted outside the swirl chamber, perpendicular to the axis of the arc. The place of the Weiss cathode disk is occupied by a metal orifice plate. Water from the swirl chamber escapes in a thin film around the edge of the orifice, and flows over the outer surface of the plate, protecting it from flame erosion. The opposite end of the swirl chamber is closed by a metal bush, carrying the anode.

The arc is struck by sliding the anode rod forward along the axis of the vortex channel, until it touches the tip of the cathode. It is immediately drawn back into the vortex channel, thereby establishing the characteristic constricted arc. (The momentary short circuit current is limited by series resistances in the external circuit.)

The arc heats the water surface, causing vaporization. This tends to raise the pressure within the vortex channel and blows out a jet of hot gases through the open end. This jet of plasma extends five centimetres or so beyond the cathode, and looks something like an oxy-hydrogen welding flame. Since the applied electric field does not extend beyond the cathode, it is possible to hold a test piece in the plasma jet without disturbing the operation of the arc.

Within the bright central core of the jet, the temperature is of the order of 10 000° C, and heat transfer rates of 300 cal cm^{-2} s^{-1} have been obtained for specimens of 6 mm diameter. These figures apply to the jet of plasma issuing from a 7 kW arc of length 2·7 cm between electrodes, contained by a vortex channel of 1 cm diameter.

Stabilization. The first essential for stable operation of a water-constricted arc is a uniform stable water vortex. This depends largely on keeping the rotational speed of the water in the swirl chamber as high as possible. The walls of the chamber are designed for minimum drag and a smooth exit is provided by the orifice plate. Water is admitted by two tangential jets, of 0·5 mm diameter, which are faired into the walls. With a water mains pressure of three or four atmospheres these fine jets allow high swirl speed, without the embarrassment of an excessive volume of water to be exhausted through the orifice.

The second requirement is electrical stability. Voltage fluctuations frequently occur in high current carbon arcs owing to the tendency of the cathode spot to wander over the whole area of carbon that is hot enough for thermionic emission. The use, as cathode, of a ⅛ in. graphite rod, projecting only ¼ in. from a water-cooled copper holder, allows the cathode spot to be confined to the hot tip of the electrode.

Finally, it is necessary to control the current by providing adequate external resistance in series with the arc. Using a 210 V d.c. main supply, satisfactory control is obtained by dropping about 100 V across the external resistance.

OPERATION OF ARC

Electrical characteristics. For a given geometry, the arc behaves approximately as a constant voltage device. Over the range used by the author, large changes of arc current cause only slight changes in the potential difference between the electrodes. If the distance between the electrodes is altered, the p.d. naturally shows a corresponding change. Burhorn, Maecker and Peters(2) have published complete characteristic curves for their design of water-constricted arc. The author's results are in reasonable agreement with their curve for an 11 mm vortex.

Another factor affecting the electrode p.d. is the atmosphere around the arc. This can be modified by injecting any chosen gas.

Effect of arc atmosphere. To examine the effect of varying the atmosphere around the arc, modifications were made to the metal bush carrying the anode. A passage was made so that gases could be blown into the vortex channel, along the narrow annular gap surrounding the anode.

It was found that a small flow of air (2 to 4 l./min), passed into the vortex channel, caused the arc to burn much more quietly. The constricting effect of the water was somew
reduced, and so was the p.d. between the electrodes.
jet of plasma became broader and of more uniform brightn
These effects were even more noticeable when argon
introduced. This gas reduced the electrode p.d. by as m
as 30% in some instances. Nitrogen, oxygen and helium
gave results similar to those for air. When hydrogen
introduced, the effects were quite different. The electr
p.d. increased by 30% in some cases, and the arc fl
appeared to be more severely constricted.

Another noticeable effect of the arc atmosphere conc
carbon evaporation from the anode.

Carbon evaporation from the anode. When the tip of
anode is examined, after the arc has been run for sev
seconds, a deep crater is usually observed. Finkelnbu
reported a similar effect for his high current carbon arc, w
freely burnt in air. He suggested that the crater was for
by evaporation of carbon from the end of the anode, du
intense heating by electron bombardment at high cur
densities. He found, as the author has, that the ra
carbon loss is not altered much by running the arc in ox
or nitrogen in place of air. Substituting argon, Finkelnb
found that the rate of carbon loss for a given current
considerably reduced, as was the p.d. across the electro
He suggested(4) that argon behaved as a gas of low ioniza
potential (about 4 V), owing to the presence of metast
atoms, formed by radiation from the arc. This effect c
reduce the "anode drop" p.d., and thus reduce the heati
the anode by electron bombardment.

The author found a marked reduction of electrode
with argon, and also a complete absence of crater form
over the explored range of 50 to 100 A. The only othe
found to give a flat anode, without crater formatio
helium. For this gas, as for argon, a metastable st
possible, with an excitation potential about 4 V less
that of ionization.

COMMENTS ON THE EFFECTS OF ATMOSPHER

The explanation of these various results is not at all cer
Possibly one might imagine that gases of low thermal
ductivity could form an insulating layer between the
flame and the water surface, thereby reducing thermal
striction. Hydrogen, having high thermal conducti
would then be expected to increase constriction of the
flame. This agrees with experimental observations.

If Finkelnburg's suggestion of metastable atoms is the
explanation for the behaviour of argon, one might ex
somewhat similar effects for helium. On the other hand,
high conductivity of helium would tend to increase the
constriction and raise the electrode p.d. Perhaps the s
drop of p.d. observed results from the opposition of
thermal conductivity and low effective ionization potent

USES OF THE 7 KW PLASMA JET

This apparatus has been used to compare the behavio
refractory materials under high heat transfer conditi
The experience gained has enabled equipment for opera
at 70 kW to be built. It is hoped to describe this at a
date.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the generous hel
Dr. Latham, of the Imperial College of Science and T
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Laboratory and workshop notes

chniques for measuring the density of a porous solid by displacement of a liquid

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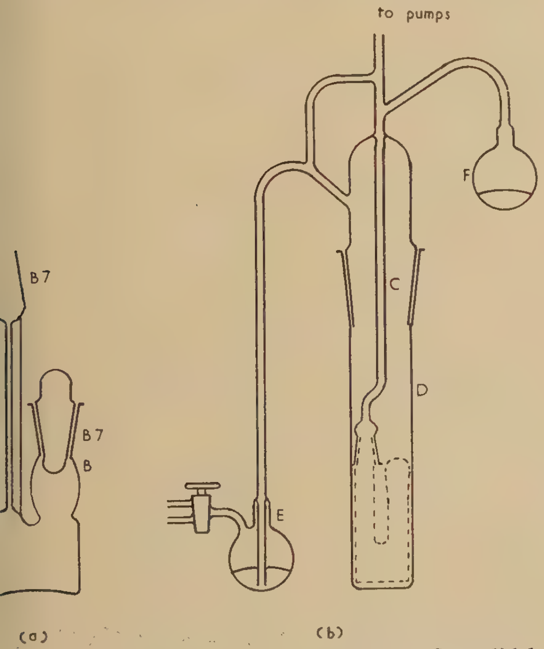
[*Note received* 8 *December*, 1958]

; a recent investigation(1) of the formation of porous
on metals in oxygen at elevated temperatures, it was
ıry to measure the density of the detached oxide scale
mersion in mercury and in carbon tetrachloride.
ıry at a pressure of 1 atm will only enter pores of
greater than about 50 000 Å, while carbon tetrachloride
ter all but the finest pores.)(2)

two techniques described below were developed in
o measure accurately the density of the small amount
le (equivalent to about $0{\cdot}3$ cm^3) which was available.
andard deviations of five values of the density of
l spar (using approximately $0{\cdot}9$ g for each determina-
ı mercury and in carbon tetrachloride were respectively
, and $0{\cdot}3$%; the mean values of the density in either
agreed within the standard deviation with that obtained
uecas and Casado.(3)

ıercury. The density bottle shown in Fig. 1(*a*) had a
e of about 5 cm^3 and was closed with a B7 stopper at



1. Method of measuring the density of a solid by immersion in mercury

capillary tube *A* of length 5 cm and diameter $0{\cdot}04$ cm
tted with a B7 cone at its upper end. For a density
ıination, the bottle containing a known weight of solid
ched to tube *C* [Fig. 1(*b*)] by an ungreased B7 cone
ocket and the outer tube *D* placed in position. After
outgassing the solid at 110° C to a pressure of 10^{-4} to 10^{-5} mm of mercury, the bottle is allowed to cool and several cubic centimetres of mercury are admitted from the reservoir *E* in order to support the bottle when full of mercury. Mercury is then distilled from the flask *F* whence it is condensed and allowed to drip through the capillary *C* into the bottle. Since all the oxides under investigation floated on mercury, it was necessary to fill the bottle completely before removing it from the vacuum system. The bottle is placed in a thermostat at 25° C, excess mercury is withdrawn and the liquid level in the capillary is measured with respect to a standard mark; finally the bottle is weighed. To prevent an air pocket forming below the stopper at *B* the mercury should be near the top of the capillary tube.

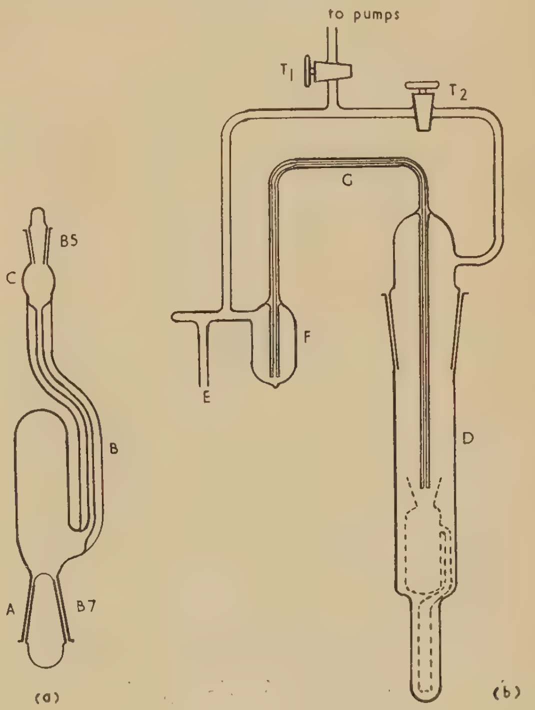


Fig. 2. Method of measuring the density of a solid by immersion in carbon tetrachloride

In carbon tetrachloride. The density bottle described above was not suitable for use with carbon tetrachloride because of evaporation losses through the stopper; accordingly, the following method incorporating a mercury seal was adopted. The density bottle, shown in Fig. 2(*a*), had a volume of about 5 cm^3 and was fitted with a B7 stopper at *A*; the capillary tube *B* of $0{\cdot}04$ cm diameter was closed at *C* by a B5 cone and socket. For a density determination the bottle containing the solid is placed in an inverted position [Fig. 2(*b*)] in tube *D*, and after outgassing, tap T_1 is closed. The break-seal on a bulb at *E* containing about 10 cm^3 of outgassed carbon tetrachloride is broken and the liquid is distilled into bulb F; tap T_2 is then closed. Momentarily cooling of the lower end of tube D in liquid oxygen proved sufficient to start the liquid siphoning through the 0·2 cm diameter capillary tube G into the density bottle. After filling, the latter is removed from the vacuum system and a weighed amount of mercury (about 5 g) added through the socket at A, the stopper is inserted and the bottle then inverted. The bottle is allowed to stand, usually overnight, to allow carbon tetrachloride to enter the pores of the solid and to enable carbon tetrachloride trapped below the mercury to evaporate. A rubber cap is then placed over the socket at A and the bottle is placed in a thermostat at 25° C. Excess liquid is withdrawn and the level of carbon tetrachloride in the capillary tube is measured from a standard mark. Finally the stopper at C is replaced and the bottle is weighed.

Both methods have the disadvantage that it is not possible to determine the weight of solid after outgassing. In the present work all the oxides had been prepared in dry oxygen and were handled in a dry box so that any error from this source is considered negligible.

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Extensometer for recording the slip of riveted joints under load

By S. A. V. Swanson, Ph.D., D.I.C., B.Sc.(Eng.), A.C.G.I., Engineering Development Laboratories, Bristol Aircraft Ltd.*

[*Note received* 27 *November*, 1958]

In tensile testing of aircraft structural materials, it is usual to measure, in addition to the maximum (ultimate) stress, the stresses corresponding to certain specified permanent deformations, known as the proof stresses. Proof stresses are normally derived from a stress-strain curve by marking the specified permanent deformations as offsets from the elastic portion of the curve, and finding the stress corresponding to each offset.

Similarly, with rivets or other fasteners loaded in shear, it is desirable to know the proof loads causing specified deformations of a given joint, as well as the load causing failure. In principle this may be achieved as for the tensile proof stresses, by obtaining a load-slip curve analogous to the tensile stress-strain curve. With the two-rivet single shear specimen normally used, the slip of the two plates under load can be measured by scribing a line across each edge of the specimen, and observing with vernier travelling microscopes the relative movements of the two halves of each line at the joint surface, as indicated in Fig. 1. This laborious method is practicable only at room temperature, but has been the only method which eliminated the errors arising from the inevitable bending of the plates out of their original plane as the load is increased.

The instrument shown in Fig. 2 overcomes this difficulty by using knife-edged yokes A which are clamped, one to each plate, adjacent to the overlapped portion. Pins B have their centre line colinear with the knife edge C, and thus any rotation of the plates is not transmitted to the forks D, which move differentially by the amount of the sliding between contacting surfaces of the two plates, plus the extension o plates between the rivets and the yokes, plus the neglig vertical component of the out-of-plane rotation of the pl Forks D are fixed to arms E, which, supported on frictio crossed-spring pivots F, transmit the movement to a differe transformer G. By connecting this, and a strain-gauged el

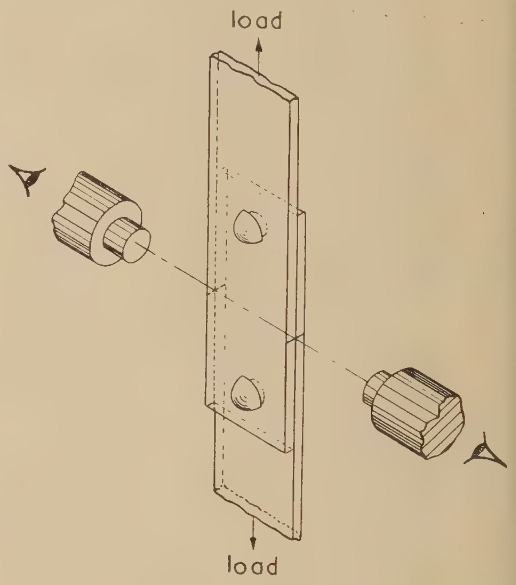

Fig. 1. Measurement of slip with microscopes

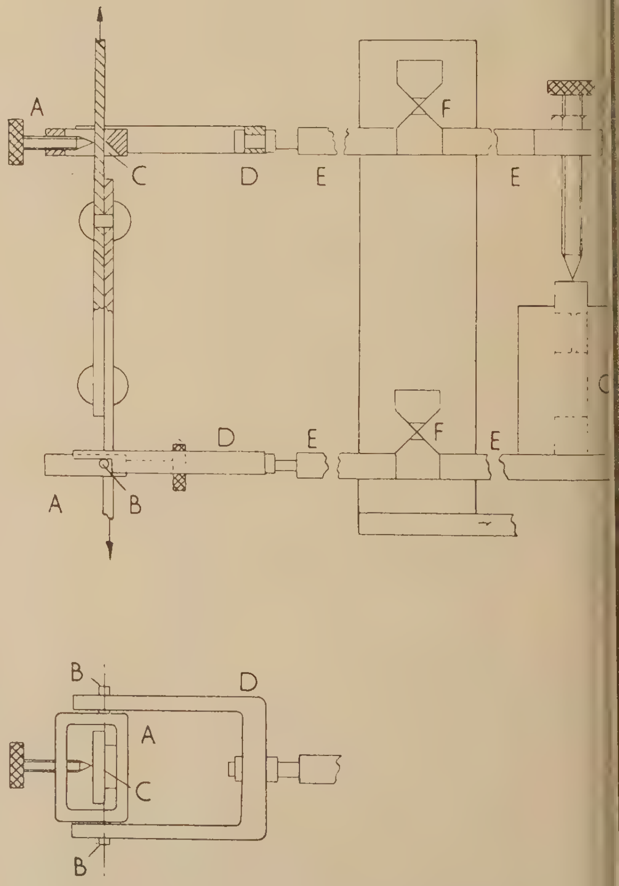

Fig. 2. General arrangement of extensometer

ided in series with the specimen, to a function plotter, p curves are produced automatically.

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* Now at Mechanical Engineering Department, Imperial College, London.

all normal rivet and plate combinations, the general on of the plate (excluding the local deformation round et holes, which is part of the joint deformation being ed) is elastic and therefore linear even up to the failing the rivets, and therefore causes no error in the proof lerived from the load-slip curves, but a correction can le if the actual joint slip is required.

noving the entire extensometer vertically, clear of the rea, and introducing links, parallel to the length of the en, between pins *B* and forks *D*, the joint area is made ble for heating by radiation when tests on heated ens are required.

instrument enables rivet proof loads to be obtained oughly the same ranges of temperature and loading as proof stresses for tensile specimens.

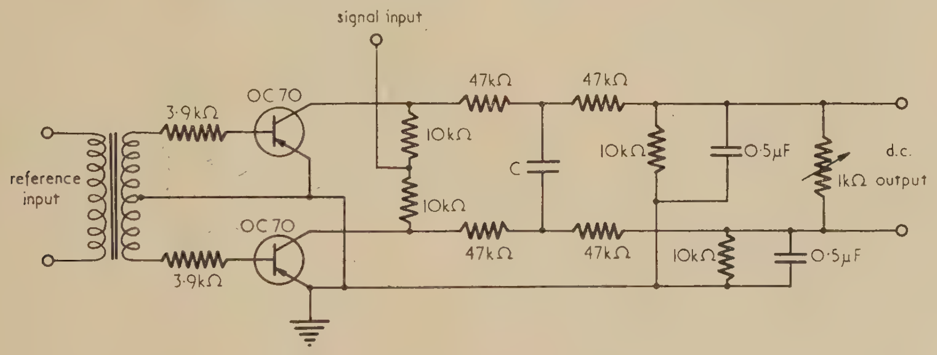
nowledgement is made to Mr. G. L. Newton, B.Sc., erformed the detailed design and development, and to Aircraft Ltd., for permission to publish this note.

Drift-free phase-sensitive detector

. A. Faulkner, Division of Tribophysics, Common-
th Scientific and Industrial Research Association,
University of Melbourne, Australia

[*Note received* 18 *November*, 1958]

hase-sensitive detector described here was developed e in nuclear magnetic resonance measurements. The ing is done by two transistors type OC70 (see figure),



Drift-free phase-sensitive detector

he signal applied to the collectors and a sinusoidal nce voltage applied in alternate phases to the bases. two halves of the switching cycle the transistor impe- is alternately very large and very small compared with kΩ load, so that variations in the transistor charac- s with temperature have very little effect. The magni- of the reference voltage is adjusted until the collector orms, monitored with the integrating capacitor *C* nected, show that correct switching is taking place; this at about 1 V r.m.s. but the value is not at all critical. ze of the integrating capacitor *C* depends on the band- required, 100 μfd giving a bandwidth of 0·2 c/s.

circuit has been in use for some time in this laboratory letector of weak nuclear magnetic resonance signals. mally works with an input signal adjusted to about 2 V o-peak, and with its output directly connected to a V quick-acting recorder (by Cambridge Instrument Co., The d.c. output, with the output control set at its num and no signal input, is less than 0·02 mV and no change in this value has been observed. From this it may be assumed that any d.c. drift is less than 5 μV. In other applications where the signal/noise ratio is more favourable, a considerably greater output voltage could be obtained and there is no reason to suppose that the drift would be any greater than in the present application.

The attachment of fine fibres with electro-deposited metal

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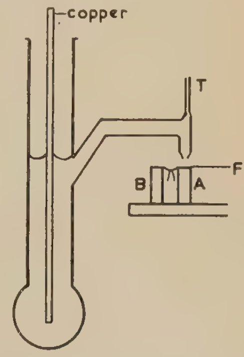
[*Note received* 12 *December*, 1958]

For some experiments with molecular beams, a torsion balance was needed which was constructed entirely of metal with a platinum torsion fibre 3μ in diameter. As the balance was to be used at high temperatures *in vacuo*, the fibre had to be attached to the balance by a method giving electrically conducting conducts which could be heated *in vacuo*. Solders with low melting points could not therefore be used but the attachment of the fibre with electro-deposited copper proved entirely satisfactory.

In the figure, *A* is the support to which the fibre *F* is to be fixed. An additional outer support *B* was placed close to *A*, as shown. A similar arrangement of supports (*A′* and *B′*) was used at the other end of the fibre. The fibre was first fixed to *B* and *B′* with wax and the hanging of a small rider of copper wire on the fibre between *A* and *B* and between *A′* and *B′* brought it into close contact with the supports *A* and *A′*. The fibre was then fixed to each of these supports by placing a drop of plating solution on the support and over the fibre and passing an electric current, using the electrode vessel shown in the figure as anode and the support as cathode.



Electrode vessel for the electro-deposition of copper. The tube *T* allows any gas formed by electrolysis to escape

The drop, meanwhile, remained attached to the electrode vessel. With an acid copper sulphate plating solution, a layer of copper was deposited on the support, and in 2½–3 h this totally enveloped the fibre and fixed it firmly to the support. The area of each support was about 0·1 cm^2 and a current of 0·8 mA gave suitably adherent deposits. The anode vessel acted as a reservoir of solution, and the proper adjustment of the liquid level prevented siphoning of liquid into or out of the drop on the support. The fibre could be fixed to each support separately, but generally, with two electrode vessels, both ends were fixed at the same time. After the deposition, excess solution was removed with a narrow strip of filter paper and the deposits were washed with distilled water and ethyl alcohol, using an artist's fine brush to apply the liquids. Excess liquid was removed with filter paper.

This method has been used very successfully with platinum fibres and with plain and metallized silica fibres. It should be of general applicability in the construction of fibre devices, particularly when electrically conducting contacts to the fibre are required and when it is necessary to heat the device to high temperatures. A torsion balance made in this way was heated to 450° C without damage. This method is also suitable for attaching any metal objects to fibres, and in the experiments was used to fix a platinum vane to the fibre. This operation was carried out with the vane supported on a jig which could be attached to the torsion balance.

On the use of coarse gratings to find the refractive indices of a doubly refracting crystal

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[*Note first received* 16 *December*, 1958, *and in final form* 25 *February*, 1959]

The methods described earlier by the authors$^{(1,2)}$ have been applied to the determination of the ordinary and extraordinary refractive indices of a uniaxial crystal. A plate of the crystal of uniform thickness t is mounted on the prism table and levelled so that the surface is normal to the beam of light from the collimator, and the plane containing the emergent ordinary and extraordinary refracted rays corresponding to a given incident ray (that is, the principal plane) is horizontal. The gratings are then mounted and the distance between them is adjusted until dark clear bands are seen against the background of the various orders of diffracted images of the slit. When the prism table is turned and the angle of incidence varied gradually, the visibility of the bands is found to change: the bands appear clear and sharp only at certain discrete angles of incidence, the reasons being those given earlier.$^{(2)}$ Here, the two systems of bands which, by superposition, cause variation in visibility, formed by the ordinary and extraordinary rays underg the lateral displacements $m_1\Delta$ and $m_2\Delta$ respectively, w Δ is the grating element. Only when the two system bands coincide do they as a whole appear clear and sh and the condition for the two systems of bands to coincid

$$(m_1 \sim m_2)\Delta = r\Delta,^*$$

where r is an integer, including zero. The bands bec vague when:

$$(m_1 \sim m_2)\Delta = (r + \tfrac{1}{2})\Delta.$$

If i is the angle of incidence and r_1 and r_2 are the angle refraction of the ordinary and extraordinary refracted ra the plate, then:

$$\mu_1 = \frac{\sin i}{\sin r_1} \quad \text{and} \quad \mu_2 = \frac{\sin i}{\sin r_2}.$$

Here, μ_1 is equal to μ_0, the ordinary refractive index, w is a constant for all angles of incidence; while μ_2, whi the apparent refractive index of the extraordinary ray, de on the direction of the ray in the crystal and on the orien of the optic axis relative to the surface of the plate.

It has been shown$^{(2)}$ that:

$$(m_1 \sim m_2)\Delta = \frac{t \sin 2i}{2}[(\mu_2^2 - \sin^2 i)^{-1/2} - (\mu_1^2 - \sin^2 i)$$

If the prism table is set to give either clear or vague ba the discrete values of the angles of incidence for $r = 1, 2, 3$, etc., are found, and the apparent refractive μ_2 is calculated from the known value of μ_1. Observ taken using a plate of calcite cut with its optic axis norm the surface are given in Table 1. The positions of the table for which the bands are vague are more critical tha positions for which the bands are clear, and so they also been noted in addition to those giving clear ba What is generally known as the extraordinary refractive of the crystal μ_e is different from μ_2, but μ_e can eas calculated for a plate cut with optic axis normal to surface from the equation$^{(3)}$:

$$\mu_e^2(\mu_e^2 - \sin^2 i) = \mu_0^2(\mu_2^2 - \sin^2 i)$$

The values of μ_e so calculated are given in the last col of Table 1. It follows from equation (1) that for the s angle of incidence i, the value $(m_1 \sim m_2)$ is proportion the thickness of the plate. In a given setting, the judgem of vagueness or clearness of bands may involve an err in the value assigned to $(m_1 \sim m_2)$. Hence, the larger value of $(m_1 \sim m_2)$, the smaller is the ratio $\delta r/(m_1 \sim$ and the percentage error in the calculated value of

Table 1. *Angles of incidence at which the bands appear vague and clear*
Value of ordinary refractive index $\mu_1 = \mu_0 = 1{\cdot}658$
Thickness of plate $= 0{\cdot}200$ *cm*

Visibility of bands	*Reading of prism table* *Clockwise*	*Anticlockwise*	*Difference* (2i)	*Angle of incidence* (i)	$(m_1 \sim m_2)$	*Apparent refractive index of extraordinary* (μ_2)	*Refractive in of extraordir* (μ_e)
Vague	261° 50′	248° 12′	13° 38′	6° 49′	½	1·330	1·485
Clear	268° 47′	240° 11′	27° 36′	13° 48′	1	1·343	1·489
Vague	276° 10′	234° 0′	42° 10′	21° 5′	1½	1·344	1·487
Clear	283° 18′	227° 2′	56° 16′	28° 8′	2	1·343	1·484

The position of the prism table for which the bands are vague is repeatable to four minutes of arc

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* The symbol $\sim$ = difference.

Table 2. *Band shift method. Change in band shift with angle of incidence*
Thickness of plate $t = 0 \cdot 200$ *cm*
Width of grating element, $\Delta = 0 \cdot 0069$ *cm*

: of bands (r)	*Displacement* ($r\Delta$)	*Reading clockwise*	*Reading anticlockwise*	*Difference* ($2i$)	*Angle of incidence* (i)	*Refractive index of ordinary* (μ_0)
2	2Δ	265° 18′	245° 32′	19° 46′	9° 53′	1·656
3	3Δ	270° 11′	240° 49′	29° 22′	14° 41′	1.651
4	4Δ	274° 50′	236° 16′	38° 34′	19° 17′	1·655

tionately less. It can be seen from Table 1 that, for ite of thickness 2 mm, only two vague and two clear ns have been obtained over the range of angle of ice 0–28° 8′. If a plate of twice that thickness is used, ague and four clear positions will be obtained for the range of angle of incidence, the ratio $\delta r/(m_1 \sim m_2)$ e reduced to one half its previous value, and the cy obtainable in the value of μ_2 will be twice as great. , thicker plates will yield more accurate results.

refractive indices μ_1 and μ_2 can also be determined ndently of each other. The bands have to be viewed h a polaroid or Nicol held between the eye and the eye- the polaroid or Nicol being so set that it cuts off the ted beam of the two polarized beams. When the table ed, the visibility of the bands does not change, and the hift method described earlier(1) can be used to find the l refractive index. It appears that there is no simpler d than this of studying how the velocity of a ray of n a crystal varies with the direction of the ray in the . The ordinary refractive index of calcite has been by the band-shift method and the observations are in Table 2.

variation of visibility of the bands with angle of nce helps in setting the plate with its principal plane ntal. The Nicol should be set with its principal plane ntal. If the principal plane of the plate is neither l nor horizontal, the visibility of the bands will vary he prism table is turned, because the Nicol will transmit elonging to both systems of bands. Hence, it is only ary to turn the plate in its own plane and set it until sibility of the bands seen through the Nicol does not vith angle of incidence.

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on of white-light fringes in the Michelson interferometer

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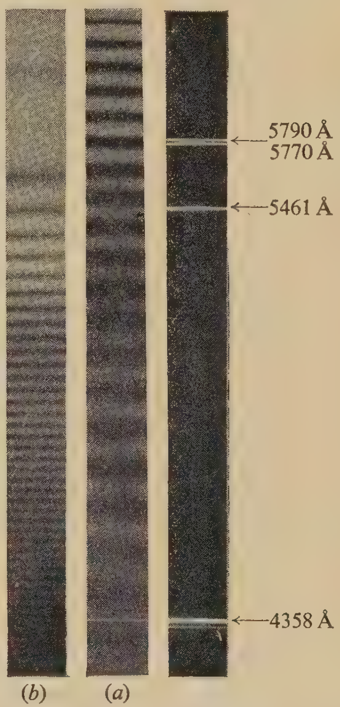
[*Note received* 1 *December*, 1958]

sual method of adjusting the Michelson interferometer at white-light fringes can be seen is to traverse the ble mirror very slowly through the position correspond- equality of the two paths, that is to say, the region the circular fringes normally seen with a diffuse e are reduced to approximately straight fringes. This d is necessarily slow and tedious and, while the task of ng the white light fringes can be simplified to some by illuminating part of the field with a high-pressure mercury vapour lamp,* there is always the serious drawback of not knowing, at any given stage, whether one is moving towards the position corresponding to white-light fringes or away from it.

A method which eliminates this uncertainty, and which has been found very useful in this laboratory, is to view the channelled spectrum formed when white light, which has passed through the interferometer, is allowed to fall on the slit of a small, direct-vision spectroscope. Because the number of bands crossing the spectrum steadily decreases as the two paths approach equality, this method yields a very convenient indication of the residual path difference, as well as the direction in which the mirror should be moved.



Channelled spectra obtained as described in the text near the mirror settings corresponding to white-light fringes (*a*) with no dispersing material in the two beams, (*b*) with a 2·6 mm thick silica plate in one beam

The method is particularly useful when it is necessary to locate the white-light fringes with a thin plate of a material having an appreciable dispersion in one of the beams. White-light fringes are then formed when the interference orders for two wavelengths separated by a fairly large interval are the same.† It can be shown that this condition will be satisfied only when a finite path difference exists between the two beams, so that, in general, circular white-light fringes will be obtained. Consequently, the normal procedure of scanning the region where straight fringes are obtained cannot be used to locate the white-light fringes. However, the fringes can be located fairly easily by watching for the appearance of the channelled spectrum as the end mirror is moved slowly in the appropriate direction from the position corresponding to equality of the two paths. To ensure maximum contrast of the bands, the interferometer mirrors should be adjusted to remove any tilt and should be illuminated at normal incidence with approximately parallel light. An extremely crude collimator will usually suffice for this purpose.

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* GUEST, P. G., and SIMMONS, W. M. *J. Sci. Instrum.*, **30**, p. 99 (1953).

† WOOD, R. W. *Physical Optics*, p. 182 (New York: Macmillan and Co. Ltd., 1934).

Because the refractive index of most optical materials does not vary linearly with the wavelength, no truly achromatic fringe is obtained in this case. For this reason, the number of bands crossing the spectrum can never be reduced to zero. The appearance of the channelled spectrum when the interferometer mirrors are set so that white-light fringes can be seen is then usually as shown in Fig. 1(*b*); the interference order passes through a flat maximum over the wavelength region corresponding to the broad central band and decreases towards both ends of the spectrum.

The authors wish to express their thanks to the Director, National Physical Laboratory of India, for permission to publish this note.

A dismountable vacuum joint suitable for bakeable glass vacuum systems

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[*Note received* 1 *January*, 1959]

A dismountable vacuum joint of the type described(1,2,3,4) for bakeable systems can be of great value for the frequent replacement of an electrode or similar structure. However, in some applications the presence of a large area of metal may be undesirable; it could, for example, influence the behaviour of an electrical discharge. To overcome the use of metal flanges, a vacuum joint has been developed in which an O-ring of lead wire compressed between glass flanges forms the seal. A joint of this type (5 cm diameter) has been baked at 300° C for long periods, the pressures achieved being usually of the order of 10^{-7} torr, and the same joint has been used many times, without failure.

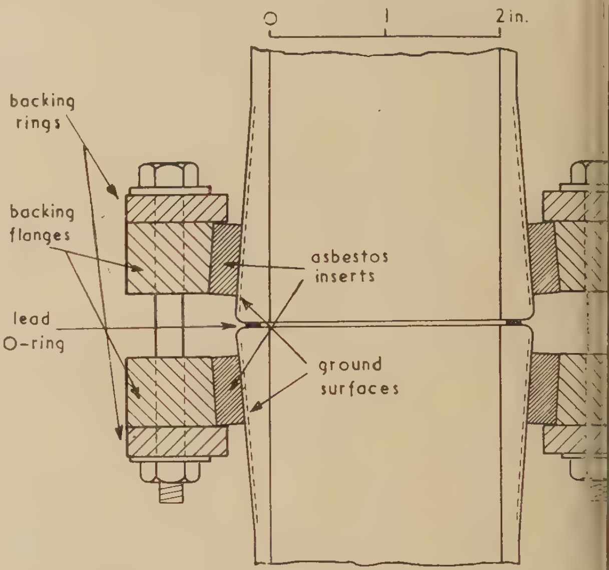
This vacuum joint was based on the joint employed between sections of industrial glass pipeline, and commercially supplied by Quickfit Visible Flow Ltd. To produce a satisfactory vacuum-tight joint with lead, the following modifications to the manufactured components were necessary:

(*a*) the cast-iron backing flanges were replaced by mild steel flanges as shown in the figure;

(*b*) the taper on the glass pipes was ground to a uniform cone so that the backing flanges pressed uniformly on the glass;

(*c*) new inserts of graphite-impregnated asbestos were cut so that they completely filled the space between the backing flanges and the glass pipes. With the inserts supplied by the manufacturers a small gap was present in their circumference at which point a crack in the glass sometimes occurred.

The ground sealing surface existing on the manufact glass flanges was used for the present vacuum joint. centre-line average roughness for one such flange was 15 (0·38 μ). Assembly of the vacuum joint was facilitate the inclusion of backing rings as shown in the figure. T prevented the backing flanges sliding over the asbestos in during the tightening of the bolts. The O-ring was made lead wire of diameter 1/16 in. (1·6 mm.) The metho joining the wire into a uniform ring has been describe Adam, Kaufman and Liley.(5) Immediately before use lead ring was cleaned by scraping its whole surface li with a knife, followed by washing in acetone.



Section through dismountable vacuum joint

When the joint was assembled, the nuts were gently tight with a spanner, moving in turn from one nut to its neigh in the same direction around the flange. An excessive to was never applied to a nut and the compression of the ring was always a gradual process. Many bolts ar advantage in obtaining an even pressure and eight were in porated in the vacuum joint now being described. Whe lead wire had been compressed so that the glass flanges separated by about 1 mm, the joint was regarded as read use.

The performance of the vacuum joint was investig when it formed part of a glass system (volume, approxim 10 l.) pumped by an oil diffusion pump (pumping sp 30 l.s^{-1}). Ultimate pressures were measured with an ion tion gauge. Without baking, pressures of 10^{-6} torr obtained. These were usually reduced after baking to range 3×10^{-7}–7×10^{-7} torr, but pressures down 2×10^{-8} torr have been recorded. The present joint been used fifteen times without failure, a new O-ring necessary each time. The leak rate of the seal could no measured with accuracy, but was certainly less than 10 torr s^{-1}. Baking to 300° C for times of up to 64 h has carried out on nine assemblies of the joint and has alway to a reduction in the system pressure. The behaviour o joint during repeated baking of the same assembly has been investigated. During baking, the bolts slack because of creep of the lead, but they were not tight after baking because there was a danger of disturbing the In fact, at this point the flanges could be removed wit damaging the seal.

ismantle the joint after use, a steel wire of diameter ater than the flange separation was made to encircle side of the lead O-ring. When this wire was stretched ins of a screw arrangement, its inward movement the flanges with safety.

vacuum joint described should have many applications nal high-vacuum work. If it is found that, in its form, its performance is not sufficient for very high work, then the performance can probably be im- by careful polishing of the glass sealing surfaces as in hod used for porcelain by Adam, Kaufman and Liley(5). as chosen for the seal because of its softness (Vickers ss, 5·4), its reasonably high melting point (327·30° C), low vapour pressure (5×10^{-9} torr at 300° C). If a baking temperature is required, then a 70/30 thallium/ loy (Vickers hardness, 8·8; melting point, 380° C) can l. However, at higher temperatures, the performance joint may be affected by a reduction in the strength of ss. If no—or only moderate—baking is required then (Vickers hardness, 1; melting point, 156° C) will be a r O-ring material.

authors wish to thank Dr. S. Kaufman for his interest work and for many helpful suggestions. They are also d to Dr. T. E. Allibone, F.R.S., Director of the ch Laboratory, Associated Electrical Industries d, for permission to publish this research note.

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ectrostatic vibrator with a highly stable centre of oscillation

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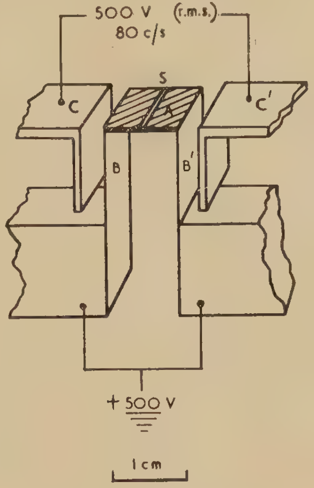
e first received 22 *December*, 1958, *and in final form* 13 *February*, 1959]

l instruments, in particular those which operate on a netric principle, frequently employ a slit or pinhole scans or is scanned by a real image. It is to this end electrostatic vibrator has been developed.

electrostatic vibrator consists of two parallel spring trips BB' (see figure), 12·7 mm long and 0·028 mm each rigidly fixed at one end, with a glass plate A, mm thick and 10·0 mm square, rigidly cemented n their free ends. The glass plate can oscillate in a on perpendicular to the plane of the strips BB' and, all amplitudes of vibration, remains almost in the of its undisturbed position.

alternating potential is applied across the electrodes e spring steel strips BB' being maintained at a constant al above the mean electrode potential. The amplitude ation depends on the air gap between BB' and CC' e respective potentials on BB' and CC'; for suitable the vibrations start spontaneously. In practice the de of vibration can most conveniently be varied by the steady potential on the spring steel strips BB'. icular, if the air gap between BB' and CC' is 0·5 mm and the potentials on BB' and CC' are +500 V and 500 V r.m.s. respectively, an amplitude of vibration of 0·1 mm is obtained at a drive frequency of 80 c/s, the natural frequency being 60 c/s. The input impedance of the system at this drive frequency is about 1 GΩ and the power dissipated less than 1 mW.



Electrostatic vibrator

In the particular application at the National Physical Laboratory a slit S has been ruled on the coated glass plate A, and the electrostatic vibrator is used as the scanning unit in a microscope designed so that the position of the image of a graduation line is compared photoelectrically with the mean position of the slit. From preliminary measurements made with this photoelectric microscope, it was found that the centre of oscillation remained stable to within ±0·0005 mm over periods of at least three to four hours.

The electrostatic vibrator could have wide applications as a scanning device where a highly stable centre of oscillation is desired. Its small size, robust configuration and negligible power dissipation are added assets.

The electrostatic vibrator has been developed as part of the research programme of the National Physical Laboratory and a British Patent has been applied for. This note is published by permission of the Director of the Laboratory.

Reinforced sulphur for insulators

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[*Note first received* 3 *October*, 1958, *and in final form* 9 *January*, 1959]

The reinforcing of ordinary sulphur by adding powdered mica provides an insulant with insulating properties little inferior to pure sulphur, but possessing superior mechanical strength. The insulant is prepared by mixing four parts (by volume) of sulphur with one part of powdered mica. This mixture forms a grey mass when melted which is suitable for casting (including the casting of metal inserts in position) and can also be ground, filed or drilled. The insulant was first prepared to provide low-leakage insulators capable of withstanding 2–3 kV for making connexions with apparatus inside a screening box. Cements based on sulphur have been described previously, but the author is not aware of any reference to the use of admixtures of sulphur and powdered mica in the preparation of insulating materials.

Capacitance-coupled cell for electrolytic conductivity measurements

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[*Note first received* 12 *January, and in final form* 16 *February*, 1959]

In the measurement of electrolytic conductivity, direct contact between the metal electrodes and the solution is often undesirable. Several workers(1–3) have overcome this difficulty by the use of so-called "electrodeless" systems operating at a high-frequency a.c. These cells have external electrodes capacitively-coupled through the cell walls, and their resistance has been indicated by the losses in an associated tuned circuit. Gupta and Hills(4) and Calvert and others(5) have described methods, limited to solutions of relatively low resistance, using an audio-frequency bridge in which the electrolytic solution was in the form of a closed ring acting as the single-turn secondary of a transformer. In the present work a more orthodox form of capacitance-coupled cell was used in conjunction with a commercial audio-frequency bridge. The cell is illustrated diagrammatically in Fig. 1 and is particularly suitable for use with dilute solutions, but it can also be applied to higher concentrations.

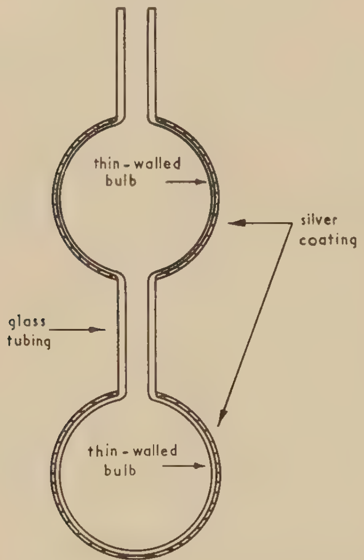

Fig. 1. The conductivity cell

For satisfactory measurements the impedance of the coupling capacitance must be much less than the electrolytic resistance which is to be measured. This condition was achieved by constructing the cells of two large thin-walled glass bulbs, less than 0·5 mm thick, which were joined by a piece of glass tubing. The bulbs were coated on the outside with an adherent layer of silver which was produced by the use of Melton silver solution. Connexions were soldered to the silver and the bulbs were protected by a coating of Araldite resin. Two such cells were made, details of which are given in the table.

Details of conductivity cells

Cell		1	2
Bulb diameter (cm)		4	7
Electrode area (cm^2)		50	154
Conduction tube	*Length (cm)*	22	4·
	Diameter (cm)	0·2	1·
Coupling capacitance C_2 *(pF)*		305·2	885·7
Residual resistance R (Ω)		3675	1655
Cell constant at 25·0° *C* (cm^{-1})		568·5 ±2·5	5· ±0·
Calibrated range at 25·0° *C* (Ω^{-1} cm^{-1})		0·1 to 0·0001	0· 0·

The bridge used in these investigations was obtained from the Wayne Kerr Laboratories Ltd. and measured the equivalent parallel conductance $1/R$ and capacitance the circuit at a frequency of 10^4 rad/s. The equiv circuit of the cell was taken to be as Fig. 2. Associated the electrolyte resistance R_1 is a small capacitance C allow for any stray capacitances and possible electroche effects; C_2 represents the combined capacitance of th walls and R_2 is a small resistance representing the die power factor.

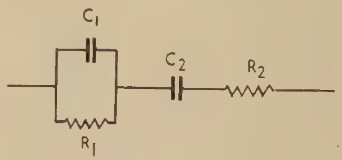

Fig. 2. Circuit diagram of the conductivity cell

If R_2 is neglected then the parallel equiv resistance and capacitance of the circuit are given by

$$\frac{1}{R} = \frac{R_1}{R_1^2(1 + C_1/C_2)^2 + (1/\omega^2 C_2^2)}$$

$$C = C_1 \cdot \frac{R_1^2(1 + C_1/C_2) + (1/\omega^2 C_1 C_2)}{R_1^2(1 + C_1/C_2)^2 + (1/\omega^2 C_2^2)}$$

From these two equations the electrolyte resistanc obtained in terms of the bridge readings $1/R$ and C, the coupling capacitance C_2.

$$R_1 = R(1 - C/C_2)^2 + (1/\omega^2 C_2^2 R)$$

This equation has been found convenient to use over whole of the resistance range studied. Since R_2 and C both small the whole of the stray capacitance may included in C_1, while the dielectric loss factor of the equat may be included in R_1.

The value of the coupling capacitance was measure filling the cell with an electrolytic solution of very resistance, e.g. 5 N hydrochloric acid. The coupling cap tance was then read directly off the bridge. The resis component R_2 was found by determining R_1 for a num of solutions of known specific conductivity and extrapola to infinite conductivity. Values of R_2 obtained in this were consistent with those expected from the power fa of the glass. The cell constants were found from mea ments with known solutions covering a wide range of ductivities and were consistent to within 1% stan deviation.

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laption of a Dick microscope for orientating crystal fragments

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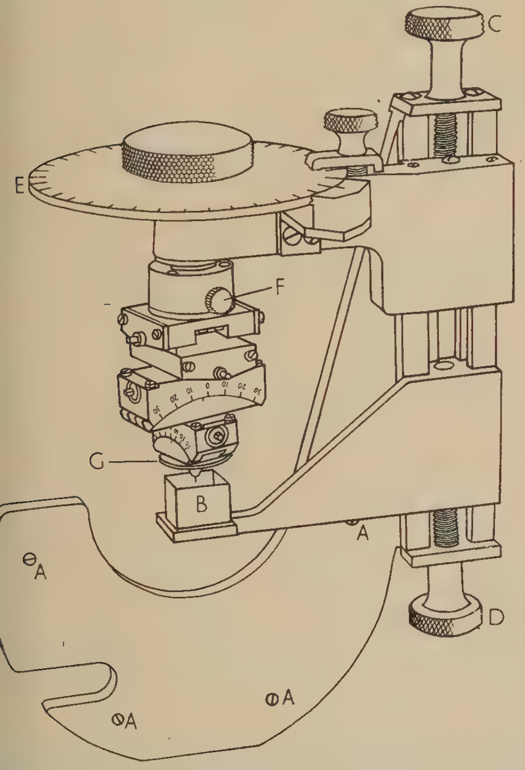
[*Note received 23rd January, 1959*]

tal fragment showing neither faces nor cleavage may kward to orientate for X-ray photography. If it is arent and birefringent, the task can be facilitated by etting up the crystal optically with the apparatus ed here. Subsequent orientation by X-rays is thereby ied or, in favourable cases, eliminated. The equipment o useful for relating optical and crystallographic ons in monoclinic and triclinic crystals. Miers* has sed a similar arrangement for determining the optic ngle.



k microscope attachment with cell and goniometer head in position

ick polarizing microscope, which is characterized by a stage and rotating polars, is mounted horizontally. ge is replaced by a device, fixed by the screws *A*, which orates a vertical spindle to take an inverted goniometer and a rest for a plane-sided glass cell *B*. The latter ns a liquid in which the crystal fragment is immersed. pindle and cell can be raised and lowered by means of the worm drives *C* and *D*. A horizontal circle *E* attached to the spindle is graduated on its upper surface in the opposite sense to the circle of an X-ray goniometer. Holes on the spindles of the two instruments locate the position of the retaining screw *F* relative to the scale zeros, enabling the goniometer head to be transferred from microscope to goniometer without loss of orientation.

It is an advantage to fit a small rotable disk *G* at the end of the goniometer head. The glass fibre supporting the crystal is mounted directly on the disk with wax or Plasticine and should be of such a length that the crystal is near the centre of movement of the arcs. The disk makes it easier to arrange for a particular crystallographic direction, such as the *z*-axis of a tetragonal or hexagonal crystal, to be perpendicular to the plane of the smaller arc. This in turn simplifies the adjustment necessary to bring an *x*-axis vertical after locating it with a Laue photograph.

Acknowledgement is made to Mr. G. F. Day, senior Laboratory Mechanic in the Geological Survey, who was responsible for the detailed design. This note is communicated by permission of the Director of the Geological Survey and Museum.

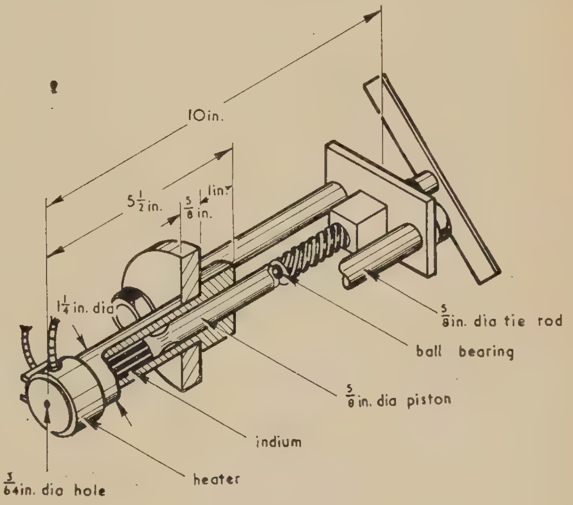
IERS, H. A. *Mineralogy*, 2nd Ed., p. 201 (London: llan and Co. Ltd., 1929).

Indium extruder

By R. L. SIMPKINS, Edwards High Vacuum, Ltd., Crawley, Sussex

[*Note received* 13 *January*, 1959]

Indium is commonly used for making metal vacuum seals by squeezing extruded wire between machined flanges. After use, the indium gasket may be reclaimed and again extruded. It is normal to prepare the indium wire by compressing the metal with a piston in a cylinder so that the indium is extruded through a fine hole. Usually, a small hydraulic or hand press must be used for forcing the piston through the cylinder, but, as a press was not readily available, a simple tool was devised for this purpose and is described below.



Indium extruder

The indium extruder is shown in the figure. It consists of a steel cylinder, having walls 5/16 in. thick, with a small hole of the desired extrusion diameter at one end. A steel piston fits closely in the cylinder. This piston is turned away behind its crown so that, should any indium flow back past the leading edge, then the soft metal will not jam the operating rod.

The end of the cylinder is heated electrically to raise its temperature a few degrees above ambient and, thus, to assist the flow of the indium metal. Pressure is applied to the end of the piston by means of a screw mounted between the members of a heavy yoke.

It is essential that the extruder should be made in the massive manner indicated in the figure if the mechanical strains encountered during compression are not to distort the mechanism.

The extruder can easily be dismounted for recharging with indium.

Acknowledgements are made to Mr. A. S. D. Barnett, technical director of Edwards High Vacuum Ltd., for permission to publish this note.

Oil-cooled electromagnet coils

By F. D. Stacey, B.Sc., Ph.D., Department of Geophysics, Australian National University, Canberra, A.C.T., Australia

[*Note received* 26 *February*, 1959]

An electromagnet has been constructed to a design similar to that of Sucksmith and Anderson* but with oil-cooled coils which permit operation at substantially higher power. Water-cooling jackets on the faces of the coils are ineffective and are better replaced by additional windings* because thermal contact between the windings and the water circulating in this manner is poor. Satisfactory contact is obtained by pumping the cooling fluid through the coils between the windings. The following are details of coils using this method.

Each coil former is similar to those of Sucksmith and Anderson* except that it is about 10% larger in every dimension and the inner half-inch of winding space is replaced by a grid of perforated rectangular brass strips. This grid holds the windings clear of a space into which the oil is pumped through a copper tube, of $\frac{1}{2}$ in. indernal diameter. Resistance to oil flow within this space is negligible by comparison with that in the windings, so that the flow is radial through the windings. Each coil has 32 layers of 38 turns of s.w.g. 10, "Lewmex" insulated copper wire. Between each layer and underneath the inner one, is a sheet of 0·030 in. "Elephantide", perforated with $\frac{1}{16}$ in. holes at $\frac{1}{8}$ in. centres. The windings finish about $\frac{1}{4}$ in. short of the outer rims of the coil formers. The electrical leads are continuous with the windings and pass through O-ring seals on one face of each coil. The coils are sealed by tightening strips of 20 gauge sheet steel, slightly wider than the coil formers, to neoprene rings of rectangular cross-section round the rims of the end plates. Oil flows out of the coils through 1 in. tubes soldered into the sheet-steel covers at their highest points.

In use, the coils are connected in series to give a total resistance of 4·4 Ω at 20° C, and current is supplied by a motor-generator of nominal rating 10 kW at 240 V d.c. The current through and voltage across the coils are shown on meters so that the resistance, and hence the average temperature of the coils, are continuously monitored.

A light oil (Fusus A, by Shell) is circulated by a gear pump from a 12½ gal drum which acts as a reservoir a cooled by copper tubes carrying water. With an pressure of 15 lb. in.$^{-2}$, the flow of oil through each c almost exactly 1 gal min^{-1} at 20° C. At a power of 10 the average temperature of the windings rises to a st value of approximately 38° C above the input oil tempera which is about 45° C after prolonged operation with present water-cooling system. The difference of 38° slightly reduced by the increased oil flow at higher ov temperatures. If necessary, the oil cooling could be impr considerably by increasing the flow (the coils have tested with an input oil pressure of 50 lb. in.$^{-2}$) and by a better oil-to-water heat exchanger, but the present sy is quite adequate to dissipate the maximum power (12 at which the magnet is now operated.

The field at the centre of the gap with 60° tapered- tips and 2 cm diameter pole faces is given in the table different values of gap length and magnet current.

Field intensity in kilo-oersteds at centre of gap for various lengths and magnet currents

Current (*A*)	*Field intensity (in kilo-oersteds) for values of pole gaps (in*				
	1·5	2·0	2·5	3·0	3·5
5	10·2	7·8	5·8	4·8	4·1
10	16·9	13·0	10·6	8·7	7·6
20	20·6	17·0	14·4	12·2	10·8
30	22·2	19·0	16·3	14·1	12·6
40	23·3	20·1	17·6	15·5	14·0
50	24·2	21·3	18·7	16·5	15·4

The author is grateful to Prof. W. Sucksmith for on magnet design and operation.

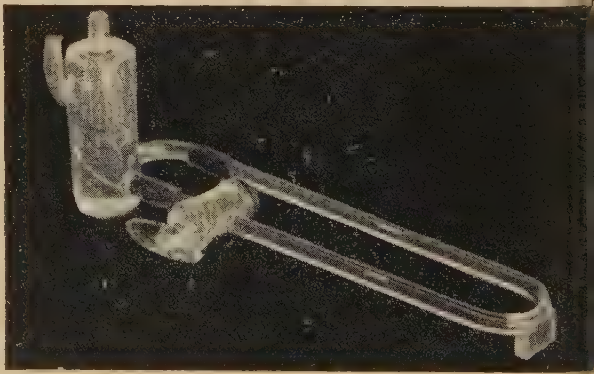
Air-bubble micromanometer developed for outdoor us

By E. Kovačič, Ing., Faculty of Civil Engineeri Ljubljana, Yugoslavia

[*Note first received* 11 *March, and in final form* 6 *Ap* 1959]

In general, sensitive liquid-filled manometers are not transportable and require to be set up on firm supports unfortunately adequate supports are sometimes difficul provide out-of-doors.

The air-bubble micromanometer described here has built into apparatus constructed for the measuremen conjunction with Pitotstatic probes, of water velocit



Air-bubble micromanometer

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* Sucksmith, W., and Anderson, S. P. *J. Sci. Instrum.*, 33, p. 234 (1956).

This manometer is based on the principle laid down usly in this *Journal** and is illustrated in the accom- g photograph.

two pots should be as nearly concentric as possible eir parallel lengths, the bent and tapered end of the ot facilitating the insertion of the bubbles after filling e appropriate liquid. The bubbles should be approximately equal in length and when undeflected should be situated in positions in each leg appropriate to the measurements to be undertaken.

With this arrangement the sensitivity of the instrument to moderate angles of tilt is very small, but zero setting is only possible by adding or removing a small quantity of liquid. When used for water flow measurements this may have to be done before the connecting leads are filled with water.

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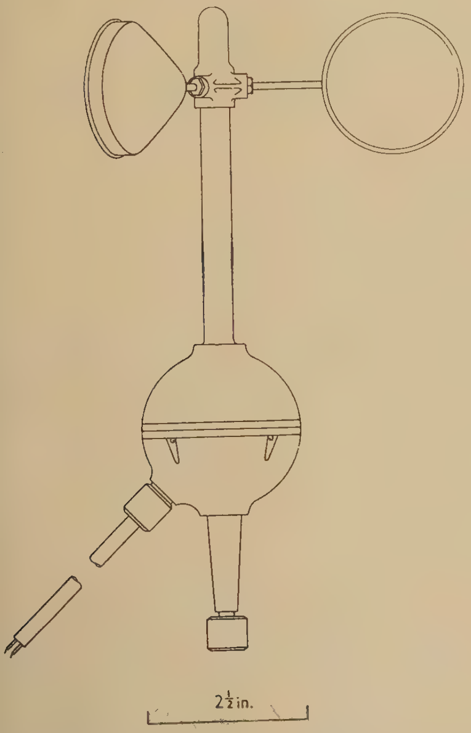
* Kovačič, E. *J. Sci. Instrum.*, **30**, p. 304 (1953).

Correspondence

housing for the sensitive cup-contact anemometer, Mk. 1

riginal Porton design(1) of the sensitive cup-contact meter, Mk. 1, used miniature ball bearings and a ed stopwatch mechanism. It appears that wartime ges were responsible for the subsequent modifications elled bearings and the clockwork indicator which are tandard.(2) The later version has a larger housing he original and it seemed likely that this would interfere he air flow. This interference would not be serious if using were cylindrical but its asymmetry gives rise to which can be serious in precision anemometry. The tude of the errors involved has been studied by Rae.(3) anemometer was modified for distant recording by n(4) who, in one model, incorporated a photocell and interrupted a beam of light to operate a telephone-message register and, in another, used a very light contact. A simpler contact system was described by Crawford(5) and the anemometer with this modification has become, in this country at least, one of the few standard tools for the study of wind structure near the ground. An electrical-contacting version of the sensitive anemometer, Mk. 1, is now manufactured commercially but it is enclosed in the same housing as the standard clockwork version. Because the housing is bigger than it need be we thought it worth while to avoid some of the wind-interference troubles by redesigning it. The new housing is shown in Fig. 1. Anemometers of this design have been in use since 1951 and have proved quite satisfactory.



line drawing of sensitive cup-contact anemometer, Mk. 1, in modified housing

The advantage of this housing, apart from its small size and approximate symmetry, are that the base can be removed completely to permit the adjustment of the contacts and that the lower part of the instrument is waterproof. Other modifications are quite minor. The small number of instruments constructed were made in bronze rather than the usual moulded plastic, the increase in weight being of little importance. The bottom taper was modified to a standard Morse No. 1 and the contact system arranged to operate 24 V telephone-message registers once in four revolutions of the cups.

We have also found that by filling the instrument housing and spindle casing almost to the top with carbon tetrachloride it can be used under water as a sensitive current meter. For this the contact system can be simplified by the removal of the gearing. We have found the cup system so fragile that it requires special care in work at sea but the linearity of the instrument and its low stopping speed in water make it suitable for the accurate measurements of flow in lakes, reservoirs and on the laboratory-model scale.

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H. Charnock
F. E. Pierce
[12 *March*, 1959]

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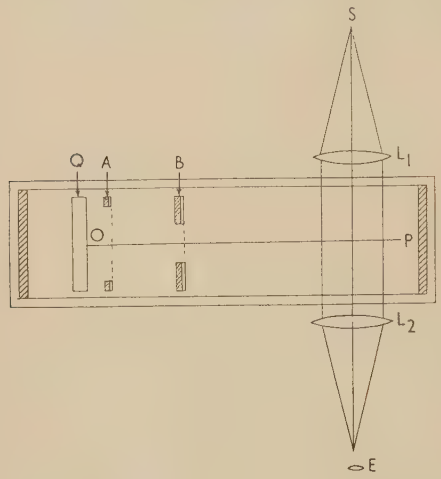
(5) Crawford, S. G. *J. Sci. Instrum.*, **28**, p. 36 (1951).

Wire grating ultrasonic interferometer

The phenomenon of successive diffraction of high-frequency sound waves at two exactly similar wire gratings, may be utilized in the design of an interferometer for the measurement of the wavelength of those waves. One of the wire gratings A (see figure) is kept fixed with its plane parallel to the surface of the piezoelectric quartz crystal Q which generates plane waves in the liquid in an optical cell. The other wire grating B is so mounted that by turning a micrometer screw it can be moved in the direction OP of the beam of sound, with its plane always parallel to the plane of the grating A. The wires of both gratings are set vertical and the grating B is so held that its wires are exactly opposite to a corresponding set of wires of the other grating, as shown in the figure. No lateral displacement of B is allowed to occur while moving it relative to A. Reflexion of sound waves at the walls of the optical cell and at the frame of the grating B is prevented by a lining of absorbing material, such as lint. Under these conditions the sound beam diffracted normally by the grating B undergoes variation in intensity, which passes through maxima and minima for distances of even and odd multiples of Δ^2/λ^* respectively between A and B, where Δ is the grating element and λ^* the wavelength of the sound waves. Lau[†] has theoretically established this result in the analogous case of diffraction of plane waves of monochromatic light originating from a narrow slit by two similar coarse transmission gratings. He has shown that the zero-order wavefront diffracted by grating A interferes with its own pair of coherent first-order wavefronts. The intensity of the beam transmitted normally by grating B is a minimum when the interfering wavelets, belonging to the pair of first-order wavefronts, arrive at each transparent element of the grating B with a phase difference an odd multiple of π, with respect to the wavelet of the zero-order wavefront, simultaneously arriving at that element. The intensity of the transmitted beam is maximum when the phase difference is an even multiple of π.



Schematic diagram of wire grating ultrasonic interferometer

Q, Piezoelectric quartz crystal; A, B, wire gratings; SL_1, collimator; L_2E, telescope.
Shaded portions represent lining of lint.

Coming to the acoustic case it is obvious that by noting the positions of grating B, for which the intensity of transmitted sound beam is minimum, one can determine interval $Z = \Delta^2/\lambda^*$ and calculate λ^*. The wire gratings be so constructed that the minimum intensity is almost ze This happens when the resultant amplitude of the two fi order wavelets is nearly equal to the amplitude of zero-order wavelet, and when the amplitude of the pair second-order wavelets is each zero, higher order wave having negligible amplitude. Both these conditions satisfied if the diameter of the wire is one half Δ.

Now the question arises how to find out whether intensity of the transmitted beam is a maximum or a mi mum. The sound beam in the optical cell will act as acoustic grating, producing the well-known Debye–Sea diffraction effect, when a horizontal parallel beam of li traverses the same optical cell in the direction SE perp dicular to the sound beam. Here S is the narrow vert slit of a collimator and E is the eyepiece of a telesc employed to view the diffraction spectra. Instead of the e piece a photomultiplier may be placed in the same posit and the diffracted light, excluding the zero order, be allo to fall on it. When the intensity of the transmitted sou beam is minimum, the diffracted light belonging to ord higher than zero may either be very weak or vanish altogeth this can be seen visually or detected by noting the deflex of a galvanometer connected to the photomultiplier. In interferometer set up by the writer, a telescope is emplo to view the diffraction spectra. Orders higher than completely vanish in the fairly sharp minima posit Grating A is of length 30 mm with wires of lead ½ diameter and 1 mm apart, having a total of thirty grat elements. Wires of lead are used because they are opa to high-frequency sound waves. Grating B consists of fi similar gratings elements over a length of 15 mm. minima positions are obtainable for sound wavelengths the order 0·2 mm, and the interval Z then works out to 5 mm. Obviously the smaller the value of Δ, the grea will be the number of minima positions.

This interferometer may be particularly useful for measurement of the wavelength of comparatively long wa in which case the usual Debye–Sears' diffraction meth may not yield accurate results as the angles of diffraction the various orders are small. Investigations are in progr to assess the accuracy obtainable and the usefulness of new interferometer.

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[17 *February*, 1959]

Shielded cathode X-ray tube

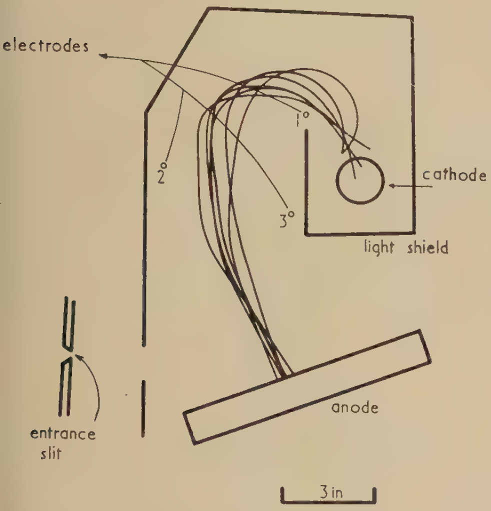
The use of a scintillation counter in the detection system a soft X-ray spectrometer rendered the conventional form X-ray tube unsuitable owing to the large quantity of visi light scattered from the anode into the spectrometer *via* entrance slit. This difficulty was overcome by placing a lig shield between the cathode and the anode to form a structu resembling those described by Dershem[*] and by Shino Suzuki and Kato.[†]

A convenient arrangement of electrodes for guiding t s round the shield was found by means of a rubber ional model and is shown in the figure. The elec- re placed close to the earthed shield, as the model ent showed that this is necessary if large electrode are to be avoided. The figure is a tracing of a aph showing six paths followed by a rolling ball, the positions being equally spaced round the circle ting the cathode. With electrode 1 operating alone rons oscillate a few times before striking it. Electrode these electrons into the field of the anode, while e 3 brings them to a focus. The model experiment that the relative electrode potentials are uncritical, mum results $V_3 = V_1$ and $V_2 = \frac{2}{3}V_1$. When allow- made for the ten times larger scale of the model the f the focus is 0·7 mm.

[†] LAU, E. *Ann. Phys.* (*Leipzig*), **2**, p. 417 (1948).

[*] DERSHEM, E. *Rev. Sci. Instrum.*, **7**, p. 86 (1936).

[†] SHINODA, G., SUZUKI, T., and KATO, S. *Technol. Rep. Osa Univ.*, **4**, No. 93 (1954).



itational model of X-ray tube showing paths of rolling balls

body of the X-ray tube is made of brass, the anode f copper and the light shield of nickel. The electrodes ned from 25 s.w.g. nickel wire and are prevented from g the shield by small mica tabs about 0·05 mm thick. portant that the mica juts into the electron stream as possible, since it can seriously reduce the efficiency lectrodes, presumably by the field distortion brought y charge collection. haracteristics of the X-ray tube are in good agreement with the predictions from the model experiment. The best ratios of electrode potentials are as predicted and the electrode currents are small. Thus with 6000 V on the anode and an anode current of 23 mA, $V_1 = 900$ V, $V_2 = 500$ V, $V_3 = 900$ V, $i_1 = 0{\cdot}8$ mA, $i_2 = 0{\cdot}1$ mA and $i_3 = 0{\cdot}6$ mA. At lower anode voltages the electrode voltages are in the same ratio, the value of V_1 for maximum current never falling below 400 V. With $V_1 = 200$ V the anode current is zero. The maximum anode current with an anode voltage of 2000 V is 25 mA, with 500 V it is 12 mA and with 100 V it is 5 mA. In the last instance the current is limited by space charge in the vicinity of the anode, while at higher voltages it is limited by the permissible energy dissipation at electrodes 1 and 3; if this dissipation rises to 2 W the electrode bends or softens sufficiently to touch the shield. The use of an electrode material of higher heat conductivity might solve this problem; nothing is gained by using thicker mica tabs as the electrode current increases rapidly with increase in distance from the shield.

The effective width of the focal line was measured by finding the X-ray flux, passing through the entrance slit on to the detector, as a function of the position of the anode. The difference between the value found, 1·5 mm, and that deduced from the model experiment, 0·7 mm, is attributed to the curvature of the focal line due to the cylindrical construction of the X-ray tube. The focal line is 7 mm high.

Advantage was taken of the control exerted by electrode 1 to pulse the electron current by applying to it a square wave of 425 V amplitude. The detection of weak X-ray signals in the presence of noise was thus greatly simplified.

The circumstance that electrode current is least if each electrode is placed close to the earthed shield suggests that the electrons are unable to follow the strongly curved lines of force due to the dipole, consisting of the electrode and its image. It follows that pairs of wires closely spaced to form dipoles could perform the same function as the electrodes described above, but to much greater effect, as some of them could be placed closer to the cathode to destroy the space charge in its vicinity and thereby increase the maximum anode current.

I am indebted to Imperial Chemical Industries (N.Z.) Limited, and to the University of New Zealand for the award of Research Fellowships.

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[27 *February*, 1959]

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New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impr products. The Institute of Physics assumes no responsibility for the statements given below: information for these has taken from literature supplied.

Germanium diode. English Electric Valve, Co. Ltd., Chelmsford, Essex.

A valve has been developed which is dimensionally the same as a previous model, but has an increased current rating of 20 A, at 35° C. It is available either as a single unit, or in multiple units fitted with fins and assembled into a stack.

As a result of this new development, it is claimed that germanium rectifier stacks can now be supplied having maximum outputs as high as 130 A, at any output voltage up to 223 V, d.c. By using various circuits it is possible to make economical use of the diodes, so that the range of stacks in production covers both current and voltage outputs in quite small steps. It is claimed that these new stacks are reliable, have a long life, and a high safety factor.

Transistorized crystal clock. Venner Electronics Ltd., Kingston By-Pass, New Malden, Surrey.

This crystal clock is designed as a compact and portable standard frequency source of high accuracy. Completely transistorized, the equipment is housed in an attractive modern case, and incorporates several plug-in stages, ending with a high quality 50 c/s synchronous clock with seconds hand. The internal clock can be omitted if desired and a 12 V 50 c/s synchronous motor can be supplied for external use.

Switched standard output frequencies of 10 kc/s, 1 kc/s, 100 c/s and 50 c/s are available, *via* a coaxial socket mounted on the front panel. The emitter follower output circuit incorporates a series resistance to prevent damage to the final transistor due to accidental short-circuiting of the output. The accuracy claimed is within 1 s per week operating in ambient temperature.

The plug-in stages are: (1) a 10 kc/s crystal oscillator, (2) two decade dividers, (3) a binary divider, (4) an output stage, and (5) a power supply (for mains operation only). These stages are manufactured by the firm. The output frequencies are of the order of 5 V peak-to-peak and have a tolerance of 3 in 10^6. Two models are provided, to serve in the temperature ranges 15 to 25° C, and 34 to 50° C respectively; each with the above output and tolerances.

The dimensions of the instrument are 12 × 8 × 7 in. and the power supply can be any of the following: a.c. mains 200/250 V, or 100/120 V, 12 V dry battery or accumulator.

Precision Wheatstone bridge. Croydon Precision Instrument Co., Hampton Road, Croydon, Surrey.

This Wheatstone bridge is intended for the precise measurement of resistance over a wide range in the standards room, laboratory or workshop. It is extremely robust and, it is claimed, will maintain its original calibration under the most arduous conditions of use. The instrument has specially designed decade switches having two parallel brushes in order to minimize contact resistance variations anc ensure long life and trouble free operation. Many o noteworthy features are included, such as a built-in s reflecting galvanometer, complete with switch oper shunt, four pairs of plug ratios, a centre zero slide wire adjustable zero setting, and provision for shorting the s wire when using uneven ratios.

The galvanometer is a taut suspended spot-reflecting t resistance 50 Ω, with coarse and fine zero adjustment. resistance coils are of manganin wire, wound non-induc on brass formers, aged by baking and stored for at l twelve months prior to adjustment. The temperature co cient is usually less than two parts in 10^5/° C.

The bridge is claimed to measure resistances with an ov range of 0·001 Ω to 10 MΩ, with an accuracy of ±0· or 0·002 Ω, whichever is the greater. It will be appreci that when measuring high values of resistance using un ratios, the accuracy will be dependent upon the conditio operation such as insulation, humidity, etc. The brid calibrated at 20° C and operates most accurately at temperature.

Instrument for making paper chromatograms. Rese Specialities Co. Ltd., 200 South Garrard Boule Richmond, California, U.S.A.

The apparatus consists of a mounting for a pipette c carriage which slides along two parallel rods. Liquid leave the pipette and, as the carriage is moved, a line of li is drawn on a filter paper underneath the carriage. It is st that uniform distribution of samples in closely constri spots or streaks is possible as a result of the rapid dryin samples and the smooth operation of the pipette positio bracket. A special non-dripping streaking pipette is avail for greatest uniformity in application of relatively l samples.

Filter paper sheets, up to the largest size (18¼ × 22½ are easily inserted into the apparatus and are held firml flexible metal fingers on either side of the line of ori The working area at the line of origin on the filter pape fully backlighted. The stream of air which impinges on under side of the paper has an adjustable temperature ra The pipette bracket pivots on the smoothly moving carr in such a way that both vertical and horizontal position the pipette in relation to the paper are conveniently c trolled. The surface of the instrument is coated porcelain to maintain maximum cleanliness of the filter pa

High-temperature adhesives. CIBA (A.R.L.) Ltd., Dux Cambridge.

To meet the demand for an adhesive to operate under h temperature conditions and having a shorter curing ti Hidux 967 has been developed. It is stated to retain at 70% of its room-temperature shear strength at 150° C.

gh its curing temperature is high (220° C), the time ired at this temperature is only two minutes. Hidux 967 two-component adhesive consisting of a Nylon film and enolic resin.

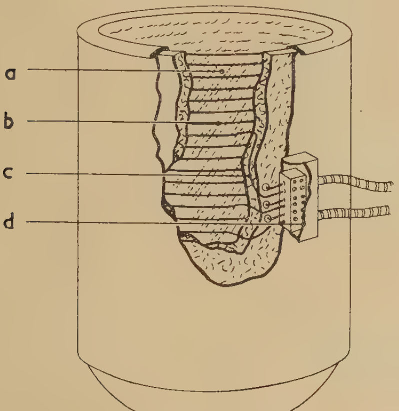
icants based on molybdenum disulphide. Rocol Ltd., Swillington, Nr. Leeds.

claimed that molybdenum disulphide comes close to the lubricant. It is resistant to heat, oxidation, light and ommon solvents and chemicals; and has a low coefficient riction, resists extreme pressures, shears readily, and ds to ordinary engineering metals and plastics.

number of molybdenized lubricants to meet the varied ands of industry are available and full particulars will be by the manufacturer on request.

tric surface heaters. Isopad Ltd., Barnet By-pass, Boreham Wood, Herts.

e surface heaters consist of four layers: (*a*) a strong ve glass cloth capable of withstanding temperatures up 50° C, thus allowing a liquid temperature of 350° C in vessel to be heated; (*b*) heating elements; (*c*) insulating erial from 2 to 4 in. thick; and (*d*) a strong stove-enamelled al cover.



Electric surface heater

hen higher temperatures of the liquid to be heated are ired, the layer (*a*) is replaced with a quartz cloth. This stands element temperatures up to 800° C and allows liquid to be heated to 600° C. Although this quartz h has a good tensile strength, it does not withstand friction ; and special protection must be provided for appliances ch do not remain in position permanently, but are nded to be applied frequently. For still higher temtures, induction coil heating has been developed. A ial flameproof heater has been constructed for use in osive atmospheres. It is claimed that all heaters mentioned ire little service and run for many years.

e heaters are designed for each situation separately, so holes for outlets and inlet pipes, thermometer pockets, can be provided. Heaters for the tops of vessels and ing jackets suitable for surrounding pipes, cylindrical els, etc., can also be provided. A small change in design erts the jackets into mobile ovens, heating jackets for ps or electrical instruments.

Screen phosphor for image storage. Ferranti Ltd., Hollinwood, Manchester, Lancashire.

A new type of screen phosphor ("Y" phosphor) with the property of storing images for periods of up to twenty minutes, which can then be released by shining infra-red on the face of the cathode-ray tube, has been developed.

A solution to the problems associated with long-persistence phosphors is found in the use of this new phosphor, the afterglow of which is under the control of the operator who can release it at any moment he wishes at an intensity which will ensure that no persistent image remains when the next field is presented. This requires provision of an infra-red source arranged so as to illuminate the whole screen of the tube uniformly when switched on, with provision for its intensity to be varied. A suitable method of doing this is by the use of a viewing hood in which a number of small filament lamps have been mounted facing the screen. Each lamp is carefully screened by means of a filter, which eliminates as much of the visible illumination as possible, while passing the short and medium infra-red light.

The phosphor combination deposited on the face of the cathode-ray tube is varied in composition depending upon the application, but its mode of action remains the same for all applications. Two distinct layers are normally provided, that nearest to the observer being the storage phosphor, and the other (the "backing layer") is a material capable of converting electron energy into blue, violet or ultra-violet light.

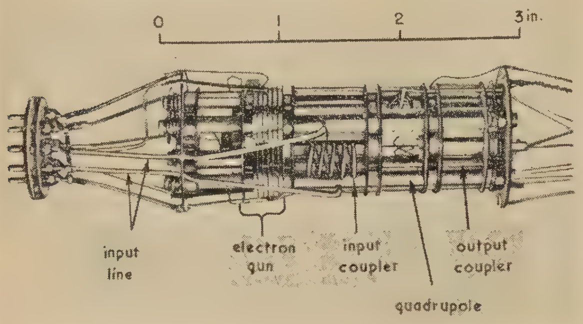
Universal supply unit. E.I.R. Instruments Ltd., 329 Kilburn Lane, London, W.9.

The unit is supplied from the mains and comprises two separate supplies built into a common panel and chassis assembly, one giving a variable voltage and the other a variable current. When d.c. is required a metal rectifier and smoothing circuits come into operation. The control of voltage and current are effected not by transformers but by heavy duty potentiometers, giving coarse and fine adjustments.

The outputs are a.c. or d.c. from 0 to 10 A; alternating or direct voltage from 0 to 1000 V at 60 mA. Outputs are floating with respect to the panel, chassis and case, which enables a more flexible use to be made of the equipment especially when voltages not connected to earth are required. All controls are mounted together with the mains fuses on the front panel. The assembly may be easily withdrawn from the case, and all wiring is carried out above the chassis. The overall size is 21 × 14 × 15 in.

Vacuum tube parametric amplifier. Zenith Radio Corporation, 6001 W. Dickens, Chicago 39, U.S.A.

An electron beam tube parametric amplifier has recently been developed for which the makers claim a noise figure of about 1 db and a gain of up to 30 db. The tube is intended for use in missile and earth satellite tracking systems, and for long-range communications. An electron gun in the tube produces a beam of about 35 μA, which drifts at low velocity (corresponding to 6 eV energy) along the lines of a 200 G magnetic field. Input and output couplers are tuned to about 560 Mc/s, the centre of the 40 Mc/s signal frequency band. The beam enters the input coupler with a certain amount of random motion. The fast wave component of this motion is given up to the input coupler and transformed into heat in the resistive part of the signal source. At the same time, the beam absorbs signal energy and carries it in the form of a fast wave, thus interchanging beam noise and input signal. The spiralling electron beam carrying the signal is passed through a quadrupole electrode energized by the "pump" which supplies 10 mW at 1120 Mc/s. One component of the a.c. field pattern in the quadrupole is a field revolving in synchronism with the spiralling electrons and causes the radii of the orbits to increase or decrease exponentially depending on their phase at the instant of entry. On the average, more electrons gain energy than lose it, and an overall gain results. The advantage claimed for this method of amplification is that the signal frequency does not affect the amplification process and the bandwidth is limited only by the input and output couplers. The gain for which the pump power is adjusted has no effect on the bandwidth or on the input and output impedances.



Fast wave parametric amplifier tube

Analogue computer. Solartron Electronic Group Ltd., Thames Ditton, Surrey.

The "Minispace" type TY864 is a completely self-contained general purpose analogue computer comprising ten drift-corrected d.c. amplifiers with all the necessary input and feedback components, potentiometers, control and patching panels and power supplies. Non-linear elements and expansion facilities are provided. The whole is contained in a cabinet 51 in. high, 20 in. wide and 30 in. deep having the high-stability power supplies mounted below desk level. Each amplifier has four summing inputs (two with a gain of 10 and two with unit gain) and either a 1 or 0·1 μF capacitor for integration associated with it. The fixed input and feedback resistors are wire-wound to 0·1% tolerance. Twenty wire-wound 10-turn helical potentiometers provide for non-integral transfers, initial conditions and transfer functions of the form $1/(1+pT)$. Four earth-free potentiometers and four diodes are provided for the simulation of non-linear functions. A centre-zero meter on the control panel monitors supply or output voltages and also acts as a balance indicator for setting coefficient potentiometers against the reference potentiometer. A ±100 V reference supply, stabilized to 0·2%, and a 10-turn direct-reading helical potentiometer are incorporated for this purpose. Although designed as a "real time" computer, an incorporated repetitive switch enables computation periods of 1, 2 or 5 s with a 1 s reset period to be obtained automatically with a trigger signal. A central overload indicator is fitted. A normal long-persistence oscilloscope may be used for display.

Pulse height analyser. Sunvic Controls Ltd., 10 Essex St
London, W.C.2.

This instrument is available in the form of a desk type co
measuring 62 × 29 × 40 in., or as one 6 ft or two
standard racks with display units at the top. A transisto
unit construction is used. Total counts can be displayed
cathode-ray tube, read in decimal form on Dekatron cou
or automatically printed out. A ferrite core storage m
is used and provides 100 channels each with a maxi
capacity of 16 binary digits (a decimal count of 65
The measurement range is 10 V with a channel widt
100 mV. The minimum pulse amplitude which can
measured is approximately 0·75 V. When totals are
played on the cathode-ray tube, the six most significant d
are given in analogue form, horizontal deflexion b
proportional to channel number and vertical deflexion t
counts in each channel. When the Dekatron indicators
used, any given channel can be selected. Alternatively,
instrument will read each channel in turn.

High-speed camera. Beckman and Whitley Inc., 973
San Carlos Ave., San Carlos, California, U.S.A.

The Beckman and Whitley "Dynafax" camera whic
intended for high-speed motion analysis is a lightweight
completely portable instrument which uses standard 35
film.

The camera caters for exposure times of between 1 and
at the maximum rated framing speed with a total w
time of 9 ms at 25 000 frames per second. Any lens inte
for use on 16 mm film and fitted in a "C"-type moun
be used in the camera.

To operate the camera, no external equipment is requ
except a common type of variable transformer. The ca
is 12 in. in diameter and 10 in. long. It is arranged
operation on any tripod.

Two-phase low-frequency decade oscillator. Muirhead and
Ltd., Beckenham, Kent.

The D-880-A decade oscillator covers the frequency r
0·01 c/s to 11·2 kc/s. The output is claimed to be cons
within 2 dB above 0·03 c/s increasing to 2·5 dB at 0·01
The circuit of this oscillator uses the principle of solvi
second-order differential equation with damping by using
integrator stages and a sign changer. Otherwise expres
the overall phase shift of 360° which is required for oscilla
to occur is achieved by two electronic integrating circ
each having a phase shift of 90°, and a sign changer ci
having a phase shift of 180°. Two outputs in quadra
are taken from the integrator circuits and are available
level of 10 V. Both outputs are directly coupled, and
d.c. content is adjusted to a very low value by pre-set cont
One output is suitable for feeding into a load of 600 Ω
is adjustable by an output attenuator down to 62 dB be
10 V; the other output is suitable for a load of 10 kΩ
is adjustable down to zero by means of a potentiom
The accuracy of frequency adjustment is stated to be 0
at 5 c/s and above—decreasing to 2% at 0·01 c/s. The
content does not exceed 1% of the peak-to-peak a.c. ou
and hum level is better than 65 dB below maximum ou
The phase relation of the two outputs is stated to be accu
to 1·5° at 1 c/s and above—increasing to 5° at 0·01 c/s.

New books

technical writer. By J. W. Godfrey and G. Parr. (London: Chapman and Hall Ltd., 1959.) Pp. 340. Price 45*s*.

lendid book this.

ne authors' claim that it is "an aid to the presentation and uction of technical literature" is fully justified; it is an llent textbook and reference book. One of them dfrey) is Editor—Technical Instruction, B.B.C., and the r (Parr), who is a Director of Chapman & Hall Ltd., and rmer Editor of some well-known periodicals, takes an e part in improving the presentation of technical informa- . They undertook the preparation of this book "to give writer of technical literature an insight into the technique resentation and production as well as laying down the ciples on which good writing is based". The authors : that it is suitable as a "concise introduction to the Inter- iate part of the syllabus of the City and Guilds of London tute's lectures on technical authorship".

ne book is a mine of information and opens with an unt of the various types of technical literature and then s with the technique of technical writing and style and entation. The next chapter is about illustrations and this ollowed by a 56-page illustrated account of all kinds of ting and reproducing processes. There are chapters on ng out the text, including mathematics, on editorial edure, and on typography. The last two chapters are on set-up of a technical publications unit and on technical orship, dealing with the business side, copyright, indexing so forth. The four appendices contain useful data and a sary, and there is a critical bibliography on the presenta- of technical information.

n p. 298 the authors say that "it is safer to be guarded ne's statements when reviewing another's works"; but in case I should hate the minor criticisms that follow to act from my wholehearted commendation of this book. pite the reading of the script and probably the proofs a number of experts, I found the sub-editing (which I er to call "copy-preparing") a little disappointing; it is to have an expert printer's reader to do this. For example, es, in., and ″ are used indiscriminately; and the hyphen is l carelessly and inconsistently; and so on.

n such a book I should expect impeccable English and while up to the usual standard of satisfactory writing by a npetent technical writer, and is very good in places, here there, a bad sentence has slipped through, which is a pity.

here are footnotes every few pages and in my view some of them should be in the text and most of the rest omitted, such as the Oscar Wilde anecdote appearing as a footnote on p. 67. On p. 100 it is stated that degrees Centigrade can be written ° C., or deg. C., or ° Cent. This is not so according to the latest British Standards (e.g. B.S. 350: Part I: 1959) and International agreement. The abbreviation "deg." is reserved for a temperature interval: thus 5 deg. C means an interval of 5 degrees Celsius and 5° C means that particular temperature on the Celsius (not Centigrade) scale. The information about blocks for illustration is most helpful but attention might have been called to the difference between reduction *to* one-third, and *by* one-third. The table showing the cost of blocks on p. 215 is misleading, as it refers to single blocks and there are "tricks", which the authors mention in another part of the book, for making several blocks together and so reducing cost. But enough of these sample minor criticisms.

I hope the publishers will one day render a service to the cause so dear to the authors by producing a series of cheap paper covered editions at a price which the ordinary technical writer (who is not usually affluent) can afford to buy with his own money for his own personal use, perhaps by collecting selected chapters together in booklet form. For instance, the authors of contributions to technical periodicals do not need chapters such as that on the set-up of a technical publications unit, but they do need much of this valuable book.

H. R. Lang.

General circuit theory. By G. Newstead. (New York: John Wiley and Sons Ltd.; London: Methuen & Co. Ltd., 1959.) Pp. vii + 144. Price 15*s*.

The approach adopted in this treatise on general circuit theory is to develop it in such a way, and with the minimum of assumptions, that the results will be applicable to all fields where similar concepts hold. The language employed is that of electric circuit theory but the author emphasizes that this is only a convenience and suitable choice of parameters to correspond with the symbols used enables other fields to be dealt with; a table gives the analogues of the several electrical parameters for mechanical, rotating, acoustical, and electromagnetic-wave systems.

General relationships rather than detailed analysis of particular circuits are the important considerations and this theme is maintained throughout.

This is another worthy addition to the well-known Methuen Physical Monographs.

A. J. Maddock.

Notes and comments

tions to The Institute of Physics

he following elections have been made by the Board of Institute of Physics:—

ows: A. Ashmore, G. B. Banks, W. W. H. Clarke, R. P. smar, W. H. Lunning, C. H. Vincent, O. M. White, . Whitemore.

ociates: F. R. Bareham, A. Bent, J. R. Brown, R. H. len, P. J. Coppen, D. Dasgupta, I. D. Dodd, S. H. nlop, L. W. Eales, S. Edwards, I. C. Fricker, A. H. oriel, R. E. Gee, O. G. Griffin, A. H. Hayward, W. S. E. kson, D. L. Lewis, I. D. Lewis, J. K. Monaghan, D. E. rgan, M. J. Morshead, S. A. F. Murrell, A. Owen, D. H. Page, G. J. Parish, J. L. Petrie, H. A. J. Prentice, B. K. Ridley, G. W. Roderick, E. C. Rogers, S. D. Rosenbaum, A. A. Runki, E. W. Simpson, G. D. Smith, N. W. W. Smith, W. R. Thomas, G. O. Walker, R. L. B. Wall, E. H. Ward.

Twenty-four Graduates and thirty Students were also elected.

Paul instrument fund grants

The Paul Instrument Fund Committee, composed of representatives of The Royal Society, The Physical Society, The Institute of Physics and the Institution of Electrical Engineers, was set up in 1945 "to receive applications from British subjects who are research workers in Great Britain for grants for the design, construction and maintenance of novel, unusual or much improved types of physical instruments and apparatus for investigations in pure or applied physical science."

Grants have just been made from this fund to:—

Dr. H. B. Barlow, assistant director of research, Department of Physiology, and Mr. P. E. K. Donaldson, technical officer, Physiological Laboratory, Cambridge, for the development (*a*) of a device for automatically improving coding of messages and (*b*) of a diffused storage sequence engine, the object being to advance knowledge of the operation of comparatively simple assemblies of nerve cells by making instruments which perform the same task as such assemblies.

Dr. E. T. Hall, senior research officer at the Research Laboratory for Archaeology and the History of Art, Oxford, in supplement of a previous grant for improvements to an apparatus with which magnetic measurements may be made with a view to dating archaeological material.

Dr. H. Motz, reader in engineering science, University of Oxford (in association with Professor G. B. Walker, professor of electrical engineering, Essex College, Assumption University, Windsor, Ontario), for the construction of a linear accelerator working at 1·6 cm (J-band).

Professor R. O. Redman, professor of astrophysics in the University of Cambridge, for the construction and testing of a thin astronomical mirror of plate glass and of a new type of support system.

Dr. P. M. B. Walker, Royal Society Research Fellow, Department of Zoology, the Ashworth Laboratory, University of Edinburgh, for the construction of a new microspectrophotometer so that it will integrate over a defined but irregular area which can be altered quickly and easily.

ICSU review

The international organization of science through National Scientific Academies or National Research Councils is not as well known among scientists as it should be. Indeed, it is often one of the Unions affiliated to this Council that initiates and organizes international conferences on particular branches of science, and in this respect the International Union of Pure and Applied Physics and the International Union of Crystallography have been active. World-wide experiments are also arranged, of which the most notable example has been the recent International Geophysical Year. There are 13 Unions under the Council and 45 countries are in this scheme.

The Bureau of the ICSU has for some time been conscious that the members of the ICSU, both national and scientific, were not being adequately informed concerning the affairs of the ICSU, and that this lack of information was detrimental to the continuing growth of the ICSU. The Unions, moreover, receive little information about each other's activities.

To help to remedy this situation a new quarterly entitled the *ICSU Review* is being published for the Council b Elsevier Publishing Company of Amsterdam under general editorship of Sir Harold Spencer Jones. The issue contains the following contributions: "What ICSU stand for?" by Alexander von Muralt; "Internat collaboration in science," by L. V. Berkner; "The i national geophysical year," by Sydney Chapman; "I national co-operation in the marine sciences," by R. Rev "Some aspects of the origins of life considered in the of the Moscow International Symposium," by N. W. In addition there are notes and announcements of recent forthcoming events.

The subscription price is 30*s*. or $4.50 or f.16 per vol (including postage) or the equivalent in other currencies

Review of the Proceedings of the Geneva Conference

The *Journal of the British Nuclear Energy Conference* publish a list of the contents of each volume of the Procee of the Geneva Conference as it becomes known. The li of the Institution of Civil Engineers will have a complet of the Proceedings which will be held for the use of mem of the constituent societies of the British Nuclear En Conference. Other constituent societies will retain for libraries only those volumes which will be of partic interest to their members but they will be willing for mem of the constituent societies to consult those volumes sh they so wish. Members of The Institute of Physics obtain details from the Secretary of that Institute.

British Standards Yearbook 1959

The latest issue of the *British Standards Yearbook* con information about the Institution and the services it of It lists the British Standards current at the 1 January, 1 and gives a brief description of each. It is available f the British Standards Institution, 2 Park Street, London, The price is 15*s*. including postage.

British Journal of Applied Physics

Contents of the July issue

ORIGINAL CONTRIBUTIONS

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First ionization coefficients in hydrogen, neon, and argon. By D. E. Davie J. G. C. Milne.
Permittivity of mixtures of zinc oxide and rubber. By N. H. Langton D. Matthews.
Theory of operation and constructional principles of a high-precision sp scopic spark source. By Á. Bardócz.
Transient temperature rise due to a line source in a semi-infinite medium, v radiation boundary condition at the interface. By H. Goldenberg.
Studies of the viscosity and sedimentation of suspensions. Part. 5.—The vis of settling suspensions of spherical particles. By D. R. Oliver and S. G.
New method for the determination of grain or crystallite size from s diffraction rings. By K. W. Andrews and W. Johnson.
Transient response of direct current amplifier systems. By R. D. Stuart.
Measurement of fibre diameter variation by optical diffraction. By W. J. O and B. Ellingham.
Methods of cleaning glass by vapour degreasing and ultrasonically ag solvents. By T. Putner.
Technique for determining the orientation of single crystals of bismuth. D. T. J. Hurle and S. Weintroub.
Transient temperatures attained in disk brakes. By T. P. Newcomb.

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Differential microdensitometer*

By A. H. Cook, M.A., Ph.D., and R. G. Hitchins, Department of Scientific and Industrial Research, National Physical Laboratory, Teddington, Middlesex

[*Paper received* 11 *November*, 1958]

The principle of a microdensitometer for the measurement of rate of change of photographic density as well as of density itself is discussed, and an experimental system is described. Examples are given of results that have been obtained in measurements of interferograms for the precise comparison of wavelengths of standard spectral lines.

a result of a study of some photographs of the graduations line standards of length, Cook(1) has shown that reciably greater accuracy in the comparison of these dards should be obtained from measurements of photo- phs than by the standard method of visual measurements micrometer microscopes. The essential point of this ly was the observation that the position at which the imum rate of change of density occurred in a photograph independent of exposure and development time, whereas r positions on the image, such as half-width points, ht be so dependent. It was further found that the maxima he rates of change of density were very sharp for photo- phs of many line-standard graduations and, in con- uence, their positions could be defined with high precision. instrument that would give a direct measurement of the of change of density has accordingly been developed and subsequently been found useful for measuring the itions and properties of images other than those for ch it was originally designed, in particular for the asurement of interferograms.

the density of a photographic image is a function $D(x)$ position x_x, then for a line image, x would be measured right-angles to the line. $D(x)$ can be expanded in a lor's series:

$$D(x) = D(x_0) + \xi \cdot D_0' + \xi^2 D_0''/2! + \ldots$$

re ξ is $(x - x_0)$ and D_0', D_0'' are the differential coefficients luated at x_0.

the image of an illuminated slit is projected on to the tograph at the position x and the light transmitted is ived by a photo-electric cell, a voltage $V(x)$ proportional $D(x)$ can be developed. Now if this slit image oscillates ight-angles to its length so that ξ is a periodic function time, then the following information may be obtained n the voltage $V(x)$.

irst, if ξ is equal to $\alpha \sin\theta$, where α is the scan amplitude θ stands for ωt, then:

$$V(\theta) = V_0 + \alpha V_0' \sin\theta + \alpha^2 V_0'' \sin^2\theta/2! + \ldots$$

he mean value Vm over a period is:

$$V_m = \frac{1}{2\pi}\int_0^{2\pi} V(\theta)d\theta,$$

$$V_m = V_0 + \alpha^2 V_0''/4 + 3\alpha^4 V_0^{\mathrm{iv}}/8\,.\,4! + \ldots$$

hat V_m is a first approximation to V_0. The error depends icipally on D_0'' and can be made unimportant by making scan amplitude small enough.

If the voltage V is fed to a rectifier which gives a positive output when θ is between 0 and π and a negative output when θ is between π and 2π, the output voltage V_d is given by:

$$V_d = \frac{1}{2\pi}\int_0^{\pi} V(\theta)d\theta - \frac{1}{2\pi}\int_{\pi}^{2\pi} V(\theta)d\theta,$$

which becomes

$$V_d = \frac{2}{\pi}\alpha V_0' + \frac{4}{3\pi}\cdot\frac{\alpha^3}{3!}\cdot V_0''' + \ldots$$

V_d is thus, to the first approximation, proportional to the mean value of D_0' along the length of the slit image.

Instead of ξ being proportional to $\sin\theta$ it may take the value $+\alpha$ when θ is between 0 and π and $-\alpha$ when θ is between π and 2π. Then:

$$V_m = V_0 + \alpha^2 V_0''/2! + \alpha^4 V_0^{\mathrm{iv}}/4! + \ldots$$

This is not such a good approximation to θV_0 as is obtained when ξ is proportional to $\sin\theta$. Similarly:

$$V_d = \alpha V_0' + \alpha^3 V_0'''/3! + \ldots$$

The term proportional to V_0''' is slightly greater than when ξ is proportional to $\sin\theta$.

V_d has, in effect, been obtained by first multiplying $V(\theta)$ by the modulating function $M(\theta)$ which takes the values $+1$ for θ between 0 and π and -1 for θ between π and 2π, and then integrating the product over a period. If other modulating functions are chosen (for instance, $M(\theta) = \sin\theta$), then, if $\xi = \alpha \sin\theta$:

$$V_d = \frac{1}{2\pi}\int_0^{2\pi} V(\theta)\sin\theta \cdot d\theta$$

or

$$V_d = \frac{1}{2}\alpha V_0' + \frac{1}{16}\cdot\alpha^3 V_0''' + \ldots$$

while, if $\xi = +\alpha$ for $0 < \theta \leqslant \pi$ and $-\alpha$ for $\pi < \theta \leqslant 2\pi$:

$$V_d = \frac{2}{\pi}\alpha V_0' + \frac{2}{\pi}\cdot\frac{\alpha^3}{3!}V_0''' + \ldots$$

Thus V_d is most nearly proportional to D_0' if $\xi = \alpha\sin\theta$ and $M(\theta) = \sin\theta$, but in every case there is an error proportional to D_0''' and higher powers. The coefficients of the term proportional to V_0''' are summarized as follows:

ξ/α	$M(\theta)$	*Coefficient*
± 1	± 1	$1/6 = 0{\cdot}167$
± 1	$\sin\theta$	$1/3\pi = 0{\cdot}106$
$\sin\theta$	± 1	$2/9\pi = 0{\cdot}070$
$\sin\theta$	$\sin\theta$	$1/16 = 0{\cdot}062$

---

* Patent applied for.

If the instrument is being used to detect the position at which D attains an extremum (that is, when D' is zero), then, if D varies symmetrically about the extremum, D''' and higher odd derivatives will also be zero and the instrument will indicate the position correctly. If D does not vary symmetrically, the odd derivatives will not necessarily all vanish with D_0' and there will be an error, but it should not be serious for a sufficiently small scan amplitude.

If the instrument is being used to detect the position at which D' attains an extremum, there is in general an error. V_d is proportional to $\alpha(D' + k\alpha^2 D''' + \ldots)$ where k lies between 1/6 and 1/16. When V_d has an extremum, then:

$$\frac{d}{dx}(D' + k\alpha^2 D''' + \ldots) = 0,$$

or

$$D'' = -k\alpha^2 D^{\mathrm{iv}}, \text{ to first order.}$$

The error of position δx is equal to D''/D''' evaluated at the extremum, that is:

$$\delta x = \frac{-k\alpha^2 D^{\mathrm{iv}}}{D'''}$$

The magnitude of this error can be estimated for a density variation of Gaussian form (such a variation is a reasonable approximation to that at the edge of an image of a trace on a line standard). For this form, D is proportional to $\exp(-x^2/2\sigma^2)$, D'' is zero when x is $\pm\sigma$ and at these values of x:

$$D''' \text{ is proportional to } 2\sigma^{-3}\exp(-\tfrac{1}{2}),$$

and

$$D^{\mathrm{iv}} \text{ is proportional to } -2\sigma^{-4}\exp(-\tfrac{1}{2}).$$

Hence

$$\delta x = k\alpha^2/\sigma.$$

If, for instance, an image is considered, for which σ is about 80 μm and a scan amplitude α of 10 μm, these values corresponding to observations on photographs of line standard traces with the instrument to be described, and if k is 1/9, then δx is 0·14 μm, a value which is to be compared with an expected error of about 1 μm in the measurement of x with a micrometer. This positional error will therefore not be serious unless α is unduly large or σ unduly small. If a photograph is taken of a spectrum line of Gaussian profile, $I = I_0 \exp\{-(x - x_0)^2/2\sigma^2\}$, the variation of density in the image is:

$$D = D_0 - \gamma(x - x_0)^2/2\sigma^2$$

over the range for which the plate characteristic is linear. γ is the slope of the plate characteristic. For such a variation: D' is $-\gamma(x - x_0)/\sigma^2$, D'' is $-\gamma/\sigma^2$ and all higher derivatives are zero. V_d therefore vanishes when D' vanishes and there is no error in the measurement of the position of maximum density. For this variation, the positions at which the extreme values of D' occur depend on exposure and have no significance.

DESIGN OF THE INSTRUMENT

In the present instrument, a diagram of which is shown in Fig. 1, a sinusoidal scan is employed and the differential voltage V_d is obtained by the use of an electronic synchronous rectifier. This arrangement replaces an earlier one in which a double image of the object slit was formed by a double mirror and each image was obscured alternately by means of a rotating shutter while contacts on the shutter axis were used for synchronous rectification. Although useful results were obtained with this scheme, it had two disadvanta the two images were formed by different parts of the opt train and it was difficult to adjust the optical system to images of equal width and intensity; and the rotating cont used for the rectification often behaved erratically.

The present system was therefore developed. The slit clear strip, about 40 μm wide, on an aluminized glass p carried in a holder attached to the armature of an elec magnetic vibrator which may be driven at a suitable freque (about 150 c/s) with an amplitude to fit the characteristic the image being investigated. A well-corrected proje lens forms an image of the slit on the emulsion of the pho graph at a reduction of four to one so that the width of projected image of the slit is about 10 μm. If the reduc is too great, the amplitude of the oscillation of the slit beco inconveniently large.

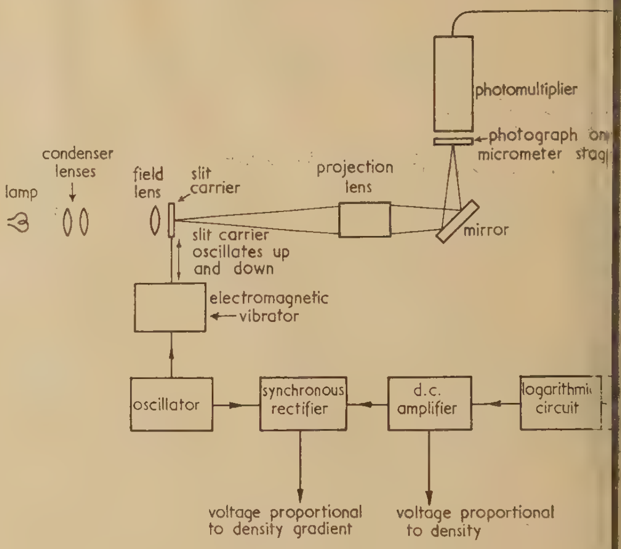

Fig. 1. Schematic diagram of instrument

Light passing through the photograph falls on a pho multiplier, the current from which flows to the cathode triode (V_1, Fig. 2) working under retarded field condition The potential difference between the anode and cathod this valve is linearly related to the logarithm of the cur through the valve over a certain range of current (Fig. 3

The voltage developed across V_1 is amplied by the amplifier V_2; the mean value of this voltage is a measur the mean density of the photograph. The zero of the den scale is arbitrary. The alternating component of the volt is amplified by the valve V_3 and is then rectified in the s chronous rectifier formed by the four germanium dic D1–D4 polarized by a reference voltage from the oscilla which drives the moving-coil unit. The signal and refere voltages are applied to the rectifier by the transform T_1 and T_2. The secondary windings of T_1 and T_2 are cen tapped and the two halves of each must be accurately ec so that balanced voltages may be applied to the ring diodes. The potentiometer RV_2 is included in the diode so that adjustment may be made for inequalities in impedances of the diodes. The direct voltage between centre taps of the secondary windings of T_1 and T_2 is p portional to the first differential of the density of the pho graphic image.

The equipment has been mounted on a toolmak microscope. Plate holders have been fitted to the wo

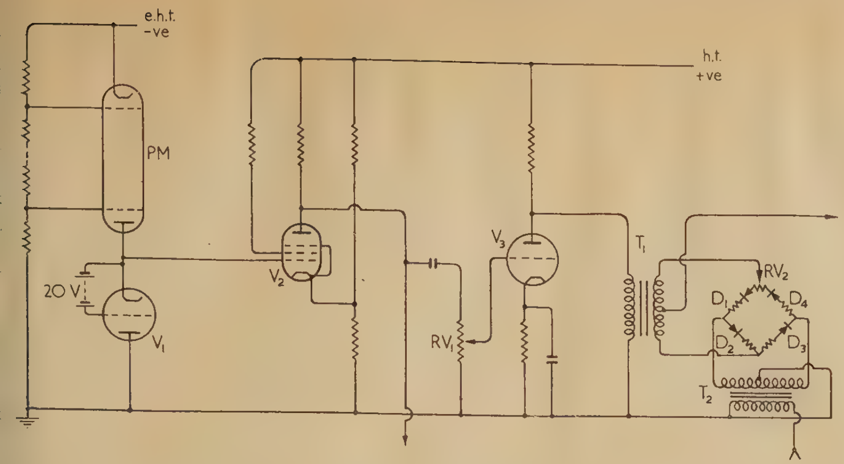

Fig. 2. Electronic circuits

PM, photomultiplier, E.M.I. type 6094C; V_1, logarithmic valve, E.M.I. type CV4003; V_2, G.M.I. type CV138; V_3, E.M.I. type CV4003.

D_1–D_4: germanium diodes, Mullard type OA5.

e which is moved by screw micrometers that can be read bout 1 μm and are correct to 1 or 2 μm. For setting he work, the slit carrier may be removed from the optical 1; a relatively large area of the photograph is then ninated and can be viewed through the microscope fitted ne instrument. The plate holder is carefully shielded to ent stray light reaching the photocell. The stage micro- r may be driven at a constant speed by a clock motor the density and gradient can be recorded on a pen rder with constant paper speed.

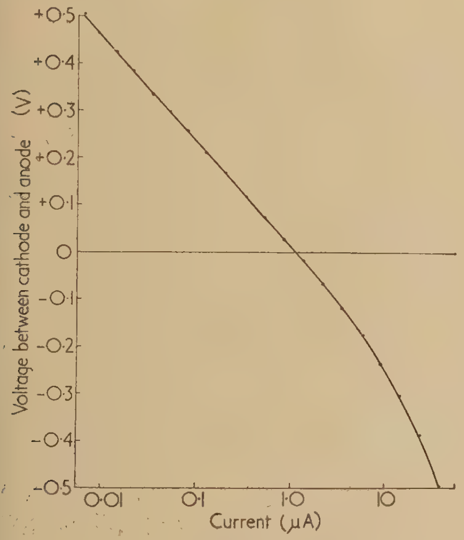

Fig. 3. Behaviour of logarithmic valve

LOGARITHMIC CIRCUIT

ne crucial part of this instrument is the logarithmic valve nd, as can be seen from Fig. 3, the relation between the nt through and the potential across this valve is rithmic over a limited range only. The effects of rtures from the logarithmic law have therefore been idered.

ne potential across the valve be given by:

$$V = V_0 + k\ln\left(\frac{i}{i_1}\right) + f\left\{\ln\left(\frac{i}{i_1}\right)\right\},$$

e i is the current through the valve and V_0, k and i_1 onstants. The function f represents the departure of the behaviour of the valve from the strict logarithmic law. If D is the density of the photograph, the current i is given by:

$$i = i_2 \exp(-KD),$$

i_2 and K being constants. If x is the distance measured along the photograph, then:

$$\frac{dV}{dx} = -\left\{k + f'\left(\ln\frac{i_2}{i_1} - KD\right)\right\}K\frac{dD}{dx}$$

It follows that dV/dx vanishes with dD/dx. The positions of maximum and minimum density are therefore identified correctly. The derivative dV/dx will also vanish if $f'\left(\ln\frac{i_2}{i_1} - KD\right)$ equals $-k$, that is, if $dV/d(\ln i)$ is zero. If dV/dx is written as $-kK\frac{dD}{dx} + \frac{df}{dD}\cdot\frac{dD}{dx}$, then:

$$\frac{d^2V}{dx^2} = \left(-kK + \frac{df}{dD}\right)\frac{d^2D}{dx^2} + \frac{d^2f}{dD^2}\left(\frac{dD}{dx}\right)^2.$$

If $f(D)$ is of parabolic form, equal to $\beta(D - D_0)^2$, say, the effect of such an error on a parabolic profile,

$$D = D_0 - \gamma(x - x_0)^2/2\sigma^2,$$

will be as follows:

$$\frac{df}{dD} = 2\beta(D - D_0) = -\beta\gamma(x - x_0)^2/\sigma^2.$$

Thus

$$\frac{d^2f}{dD^2} = 2\beta.$$

Also

$$\frac{dD}{dx} = -\gamma(x - x_0)/\sigma^2.$$

Therefore

$$\frac{d^2D}{dx^2} = -\gamma/\sigma^2.$$

The relative error in d^2V/dx^2, namely,

$$\left(\frac{d^2V}{dx^2} + kK\frac{d^2D}{dx^2}\right)\Big/kK\frac{d^2D}{dx^2},$$

is then $-3\beta\gamma(x - x_0)^2/kK\sigma^2$ which has the value $-3\beta\gamma/kK$ when $(x - x_0)$ equals $\pm\sigma$.

An idea of the order of magnitude of this error can be obtained from the characteristic shown in Fig. 3, for which $k = 0{\cdot}225$ V, and $\beta = 0{\cdot}060$ V approximately for currents greater than 1 μA. The relative error at $(x - x_0) = \pm\sigma$ is then about $0{\cdot}9\,\gamma/K$, which is of the order of unity. The non-linearity must therefore be far less than in this example if correct values of d^2V/dx^2 are to be measured. The straight-line part of the characteristic in Fig. 3 is, however, satisfactory.

The voltage-current characteristic of the logarithmic circuit is linear provided the potential of the cathode of V_1 is positive with respect to the anode. The gain of the photomultiplier should therefore always be adjusted so that this condition is satisfied, that is, the current is less than about 1 μA. At the same time, the current should not be too small or stray electromotive forces may affect the behaviour of the logarithmic circuit. It is for this reason that a photomultiplier is used because, by varying the number of stages used and the voltages applied to them, the current can be adjusted to be as large as possible, yet less than 1 μA, for a wide range of lengths and widths of the slit.

EXAMPLES OF MEASUREMENTS

Observations have been made on photographs of Fabry–Perot interferograms of the orange line of Kr–86. A photograph of such an interferogram is shown in Fig. 4. The order of interference was 206 000. Density and gradient traces across the interferogram, taken with a slit 0·2 mm long, are reproduced in Fig. 5. Table 1 contains some repeated observations made at the same scan amplitude. The diameters were read off a paper record; if the readings are made with the stage micrometer the standard deviation of a single setting is better than 1 μm.

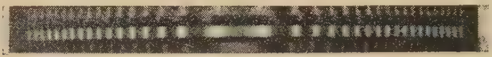

Fig. 4. Photograph of Fabry–Perot interferogram

Orange line of Kr-86, order of interference, 206 000.

Table 2 gives residuals of observations made at different scan amplitudes and the effect of structure in the photographic image is clearly apparent in the change in most of the residuals when the scan amplitude exceeds the slit width (10 μm, approximately). The records reproduced in Fig. 6 show that the detail, especially in the differential curves, is smoothed out at the greater amplitudes.

Some applications of the instrument to interferometric studies have already been described.(3) In addition, advantage can be taken of the sensitivity of the differential spect to structure in a spectrum, the power of which has shown recently in various studies.(4–6)

Table 1. *Measured diameters of 5 rings of a Fabry–P interferogram*

Scan: 10 μm

Ring number	*Diameters (mm)* 1	2	3	*Residuals from mean* 1	2
1	2·751	2·754	2·753	−2	+1
2	3·745	3·747	3·748	−2	0
3	4·517	4·519	4·522	−2	0
4	5·193	5·188	5·191	+2	−3
5	5·784	5·783	5·785	0	−1
f	0·166	0·171	0·169		

Standard deviation of a single measured diameter: 2 μm.

Note: (1) The observations were made with a pen recorder corrections have been applied to Set 1 to allow different paper speed.

(2) *f* is the fractional order of interference computed the observations.

The standard deviation includes the effects of irregularities in recorder paper speed.

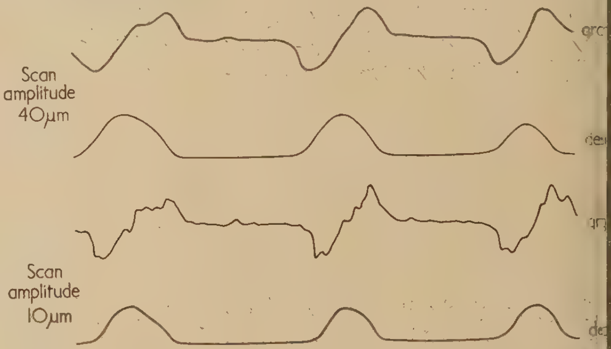

Fig. 6. Density and gradient traces across photogra similar to that of Fig. 4

Upper set: scan amplitude 40 μm.
Lower set: scan amplitude 10 μm.

ACKNOWLEDGEMENTS

Continuous advice has been received on the electr circuits from Mr. W. Wilson. The optical system designed by Mr. W. Taylor and some components

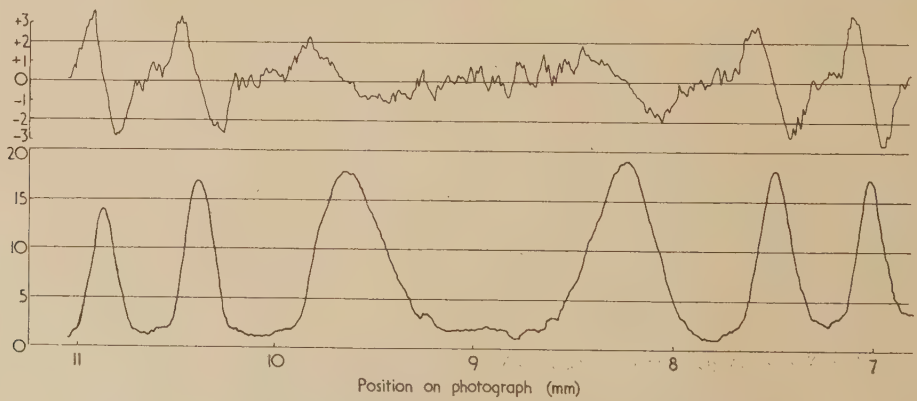

Fig. 5. Density and gradient traces across photograph of Fig. 4

Upper trace: gradient; Lower trace: density. Arbitrary units of density; Slit width, 10 μm.

Table 2. *Effect of varying scan amplitude*
(Measurements on a Fabry-Perot interferogram)

	Scan amplitude	*Residuals of measured ring diameters from mean (µm)*				
umber	5 µm	10 µm	14 µm	18 µm	28 µm	39 µm
1	−5	−3	+5	−4	+2	+4
2	+4	+7	−1	−4	−6	−3
3	+1	+3	−5	−6	0	+6
4	+11	+11	−7	−8	−8	−1
5	+1	+10	−1	−5	−4	−2
f	0·169	0·166	0·176	0·171	0·175	0·177

the fractional order of interference computed from the ring ieters.

e in the workshop of the Light Division of the Laboratory. mechanical parts were made and to a large extent designed in the Standards Division workshop by Mr. A. Cox and Mr. Goddard.

The work described forms part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory.

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Solarimeter for field use

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Using simple materials a thermopile solarimeter has been constructed with output 5·5 mV $\text{cal}^{-1}\ \text{cm}^{-2}\ \text{min}^{-1}$; resistance 13 Ω; response time 20 s; weight 35 g; dimensions 4 × 4 × 4 cm. It can therefore be used with a portable millivoltmeter for measuring reflexion coefficients, radiation within crops, etc. General equations for solarimeter performance and a simplified theory for the present design give a non-linearity of $-0{\cdot}8\%$ $\text{cal}^{-1}\ \text{cm}^{-2}\ \text{min}^{-1}$ and a temperature coefficient of $-0{\cdot}12\%$ per deg C. Outdoor comparison with a Kipp solarimeter gave $\pm 0{\cdot}03$ cal $\text{cm}^{-2}\ \text{min}^{-1}$ as the maximum deviation from the mean response with radiation up to 1·1 cal $\text{cm}^{-2}\ \text{min}^{-1}$. The standard deviation for thirty observations in bright sunshine and with overcast skies was $\pm 0{\cdot}002$ cal $\text{cm}^{-2}\ \text{min}^{-1}$. Cosine and azimuth response were improved using a larger instrument of the same design and comparisons of this with a Kipp solarimeter gave maximum deviation of $\pm 0{\cdot}02$ cal $\text{cm}^{-2}\ \text{min}^{-1}$.

INTRODUCTION

ugh the accurate measurement of temperature, humidity vind speed among vegetation and in animal habitats is possible with specially designed equipment, relatively attempts have been made to measure solar radiation as icroclimatic element, and suitable instruments are hard nd.

he two instruments in most common use for the routine surement of short-wave radiation are the Moll–zynski thermopile manufactured by Kipp and Zonen Holland and the thermopile developed by Kimball and bs and manufactured by the Eppley Laboratory in the ted States. (For convenience these will be referred to manufacturer's name.) The thermopile housing of the p has a diameter of 7 cm, a height of 10 cm and a weight ·7 kg, while the Eppley has a diameter of 20 cm and a ht of 17 cm. Neither is suitable for microclimatic work: r size restricts use within crops; and a relatively large and dy support is required if continuous measurements are e taken at a fixed position. Use of commercial instrutts for simultaneous measurements of radiation at several ts, often desirable in microclimatic studies, becomes very ensive.

solarimeter which is small, light, cheap and simple to struct has been described by Ward⁽¹⁾ who used thermistors he temperature sensing elements. That to be described here employs thermocouples in a mount with dimensions 4 × 4 × 4 cm and weighs only 35 g. Advantages of using thermocouples in radiation instruments are that no special circuitry is required as the output is fed directly to a galvanometer or recording potentiometer; and that integration of the output can be achieved by methods recently reviewed by Trickett, Moulsley and Edwards.⁽²⁾

Care has been taken not to sacrifice performance to portability and it will be helpful to precede an account of construction and performance by a discussion of criteria for the design of an accurate solarimeter.

DESIGN CRITERIA

In the Kipp and Eppley solarimeters incident radiation sets up a temperature difference between the opposing junctions of a thermopile. The "hot" junctions painted black or attached to a black surface, absorb virtually 100% incident radiation. The "cold" junctions of the Kipp remain cold because of their very high thermal capacity and because only a very small fraction of their area is exposed to radiation. The "cold" junctions of the Eppley are attached to a highly reflecting white surface. Glass domes protect the thermopile surfaces from the weather and make the response independent of wind speed.

The design criteria for instruments of similar principle are summarized below.

Linearity. The basic response equation is

$$R = \sum_i h_i(T - T_i) \qquad (1)$$

where T is the equilibrium temperature of a horizontal surface gaining heat by short-wave radiation R and losing it by conduction, convection and long-wave radiation to the surroundings. For each of these processes there will be a transfer coefficient h_i, and an appropriate sink temperature T_i. Linearity of temperature response therefore depends on the temperature dependence of the transfer coefficients and on the magnitude of the temperature difference between the receiving surface and its environment. Assuming that the environment has a uniform temperature T_0 approximately equal to that of the ambient air, equation (1) becomes

$$R = (T - T_0)\sum_i \{h_{i0} + (T - T_0)\partial h_i/\partial T\} \qquad (2)$$

The voltage E developed by the thermopile can be related to the temperature difference between junctions by an equation of the form

$$E = a(T - T_0) + b(T - T_0)^2 \qquad (3)$$

where it is assumed that the cold junctions are at ambient temperature T_0 and a and b are constants determined by the choice of thermocouple materials. The response of the instrument, defined as the output voltage per unit incident radiation, can be expressed as E/R. Non-linearity, defined as the fractional change in response for unit change in radiation is

$$\left\{\frac{\Delta(E/R)}{\Delta R}\right\}\left(\frac{E}{R}\right)^{-1} = \left\{\frac{\Delta(E/R)}{\Delta(T - T_0)}\right\}\left(\frac{T - T_0}{E}\right)$$
$$= \left(\frac{b}{a} - \frac{\Sigma\,\partial h_i/\partial T}{\Sigma\, h_i}\right)(\Sigma h_i)^{-1} \qquad (4)$$

from (2) and (3) ignoring second-order terms. In both Kipp and Eppley instruments

$$\frac{\Sigma\,\partial h_i/\partial T}{\Sigma\, h_i} > \frac{b}{a}$$

Non-linearity is between $-2{\cdot}1\%$ and $-5{\cdot}4\%$ for the Kipp(3) and $-0{\cdot}5\%$ for the Eppley [(calculated from data given by Fuquay and Buettner(4) using equations (4) and (5)]. The superior performance of the Eppley is an indirect consequence of the relatively large part played by conduction of heat from hot to cold junctions. The term $\Sigma\, h_i$ is therefore greater than in the Kipp and the two terms in the numerator of equation (3) are more nearly equal. Because the response of an instrument is proportional to $1/\Sigma\, h_i$ [equation (1)] linearity of the Eppley is achieved at the expense of sensitivity. For many practical purposes this is unimportant, but the relatively low output and high resistance of the Eppley make it too insensitive an instrument for use with a portable galvanometer in the field.

For spot readings linearity is unnecessary, because output can be uniquely related to radiation through a calibration curve, but for continuous recording linearity is very desirable, and for integration it is essential.

Constancy of zero. In terms of equation (1), constancy of zero in a Kipp-type instrument implies that radiation should not produce differential heating of the various parts of the instrument to which heat is lost from the thermopile, because unequal sink temperatures may give a spurious temperature difference between the hot and cold junctions. For example, when the glass dome and the cold junctions are not at the same temperature, long-wave exchange within the instrum will set up a temperature gradient in the thermopile e when no short-wave radiation falls on it. In the Epp type, by contrast, both hot and cold junctions lose similarly by long-wave radiation to the dome and by c vection to the air. When the instrument is screened fr radiation, conduction along the thermocouple wires bri the junctions rapidly to the same temperature although may not be precisely the temperature of the glass dome.

A first attempt to construct a small Kipp-type instrum with a relatively light thermopile (about 40 g copper) fa because the temperature of the thermopile steadily increa when the instrument was irradiated. When the exte (short-wave) source was cut off, long-wave radiation from thermocouple to the relatively cold glass dome cooled "hot" junctions below the "cold"-junction temperature giv a negative zero as great as -20% of the original reading. was then decided to adopt the Eppley principle, first emplo in solarimetry by Callendar,(5) of measuring the tempera difference between black and white surfaces, accepting risk that deterioration of the white surfaces changes sensitivity.

A further reason for adopting the Eppley design was e in making the instrument insensitive to atmospheric lo wave radiation. In the Kipp instrument this is achieve using two concentric glass hemispheres but in the Epple temperature difference between hot and cold junctio sufficiently independent of glass temperature to make provision of a second dome unnecessary.

Cosine and azimuth response. The response of a sol meter to a beam of radiation of constant intensity shou proportional to the cosine of the angle of incidence o radiation on the sensitive surface but independent of azimuth. Reflection from a surface may vary with the an of incidence and this variation must therefore be reduce a minimum using a good optical black paint for the absorb surface and a matt white paint for the reflecting surface.

Further undesirable deviations from a true cosine respo are possible with the introduction of a hemispherical g dome. In the first place, the radiation reflected from outer surface of the dome is a function of the angle incidence on the glass. But radiation received at the cer of the hemisphere is everywhere normally incident on glass and is equally reflected for all angles of incidence w respect to the equatorial plane of the hemisphere. Th retically the ideal arrangement, closely approached in War instrument, is a sensitive point at the centre of a hemisphe In practice, the advantages of this are outweighed by disadvantages of the uneven transmission of commercia available domes which have not been specially ground optical work. To reduce cost it was decided to accept th irregularities and to use a receiving surface of at least 1 c which would integrate the uneven distribution of radiati produced by striations in the dome.

Reflexion from the inner surface of the dome formin caustic surface on the equatorial plane can be troubleso when radiation is incident on the plane at angles less th 40°. Most of the energy in the caustic falls outside a cir of radius $a/3$ where a is the hemisphere radius and it is the fore desirable to restrict the sensitive surface to a circle radius $a/3$ concentric with the centre of the hemisphere.

Uniform response with varying azimuth can be obtain in an Eppley-type instrument either with a central black sp surrounded by a white annulus giving perfect circular sy metry, or with a chess-board pattern of black and wh squares as in the solarimeter developed by Ianishevsky(6) a extensively in the U.S.S.R. Experiments with a circular ving surface in which one pair of opposite quadrants painted black and the other white showed that output nded greatly on azimuth caused by long-wave radiation ved by the thermopile from the warm sector of the dome est the source of radiation. The thermopile was then signed for complete circular symmetry.

pendence of sensitivity on temperature and wind speed. temperature coefficient of thermopile instruments is l but not always negligible. The Kipp has a coefficient pproximately $-0{\cdot}2\%$ per deg C, the Eppley $-0{\cdot}085\%$ leg C; and before comparing radiation at different times ear readings should be corrected for temperature.(7) ecting second-order terms, the temperature coefficient sponse defined as the fractional change in response per change in ambient temperature is

$$\left\{\frac{\Delta(E/R)}{\Delta T}\right\}\left(\frac{E}{R}\right)^{-1} = \left(\frac{b}{a} - \frac{\Sigma\,\partial h_i/\partial T}{\Sigma\,h_i}\right) \qquad (5)$$

equations (1) and (2).

nd speed might conceivably affect the response of a imeter because the energy which it receives by radiation ultimately be dissipated by transfer to the air. If the erature of the "hot" surface is to be independent of wind l, the constant thermal resistance to the transfer of heat this surface to the dome, for example, must be many greater than the thermal resistance for transfer from ome to the surrounding air for all normal wind speeds. ractice this criterion is easily satisfied. If the receiving ce has an area A of 1 cm^2 and a transfer coefficient h 10^{-4} for loss of heat to the air by convexion and to the by radiation,(3) the equivalent thermal resistance $1/hA$ 5 . 10^3 c.g.s. units. The total thermal resistance between hermopile and the outer surface of the dome will be er than this by an amount depending on conduction igh the dome.

e heat exchange between the outer surface of the dome he ambient air can be obtained from

$$h = 0{\cdot}33(Vd/\nu)^{0.6}\,k/d \qquad (6)$$

data given by McAdams,(8) where k is the thermal uctivity of still air, V is air speed, ν kinematic viscosity d diameter. For $d = 4$ cm the thermal resistance is g.s. units for $V = 10^2$ cm/s and 22 c.g.s. units for 10^3 cm/s. It follows that in the transfer of heat from hermopile through the glass to the outer air, changes in nal resistance due to changing wind speed will be gible compared with the total thermal resistance, so that emperature of the thermopile surface will be constant iven radiation.

ectral response. The dependence on cloud amount and elevation of the spectral distribution of atmospheric -wave radiation can produce small sensitivity variations larimeters related to the absorption spectrum of the (3) Uniform absorption by the black surface can be ned over the whole spectral range using lamp black or ons optical black paint which is known to have an rption between 0·980 and 0·985 from 0·5 μ to 10 μ.(9) a white surface, magnesium oxide is used commercially this has the disadvantage of being easily damaged. lts with a thixotropic white paint showed that this was ceptable substitute for magnesium oxide when long-term lity was unimportant.

sponse time. There appears to be no fixed opinion as hat constitutes a suitable response time for a solarimeter. n calibrating and checking instruments it is convenient to have as rapid a response as possible, but this is not always desirable. When such an instrument is connected to a potentiometric recorder on a day of intermittent sunshine, the record contains so much detail that it is almost impossible to integrate by planimetry, while for spot measurements in the field steady representative readings are extremely difficult to obtain.

In practice, response time may usefully be related to the maximum lag error which is acceptable when radiation is changing rapidly in the absence of cloud. In June the maximum rate of change of radiation on cloudless days is about $4{\cdot}10^{-3}$ cal cm^{-2} min^{-2} so for a maximim lag error of 10^{-3} cal cm^{-2} min^{-1} the response time must not exceed 15 s.

CONSTRUCTION

The thermopile was constructed by a modification of Wilson and Epps'(10) technique now used in several meteorological instruments to measure small temperature differences. A 70 cm length of 42 s.w.g. constantan was loosely coiled and electro-plated with copper until the diameter had increased by 10% (by passing a current of 20 mA for 30 min). To ensure an even thickness of copper over the whole length of the wire, the plating bath was diluted until the wire resistance (45 Ω) was less than a tenth of the resistance between the electrodes. This plated wire was wound toroidally on a Perspex former (A in Fig. 1) to give 27 evenly spaced turns which were then coated with paraffin wax except for the short section pp' of each turn, 5·5 mm long. The former was returned to the plating bath and with the winding connected as anode, current was passed until all the copper along each section pp' had been removed. The copper virtually short-circuited the constantan along the plated section of the winding, and this left 27 copper-constantan junctions at the points p with opposing junctions at the points p'. The unit was then dipped in boiling water to remove the wax and cleaned in carbon tetrachloride. This elaboration of Wilson and Epp's technique was found essential for an even distribution of copper along the thermopile wires.

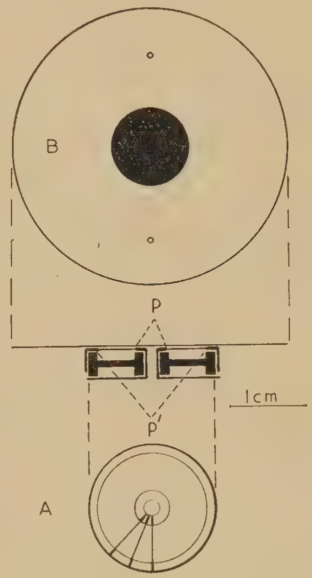


Fig. 1. Plan and elevation of Perspex former A and Paxolin disk B. The thermopile winding is shown diagrammatically with opposing junctions at p and p'

The Perspex former was cemented with Durofix to the centre of a Paxolin disk (*B* in Fig. 1 and *a* in Fig. 2), 0·15 mm thick and 3·8 cm diameter (punched with two small holes for subsequent pressure equilibration in the instrument) and the disk with former attached was immersed in chloroform for two days. The cement was unattacked but the Perspex dissolved completely, leaving only the winding attached to the disk. The disk was then cemented to a Perspex annulus *b* with the thermopile underneath (Fig. 2) and painted with a central black circle of diameter 1 cm surrounded by a white ring, using Parsons optical black and a matt white paint. The dome *c* was cemented to the annulus with Araldite that was allowed to set at room temperature to avoid straining the glass. A Perspex base *d* was secured to the annulus by three 1 in. 6 B.A. bolts *e* (which also acted as feet) with an aluminium disk *f* between the two sections intended to assist heat exchange between the thermopile and the ambient air and thus reduce the response time. Two 8 B.A. screws *g* in the annulus provided terminals and were connected to the two ends of the thermopile. Before sealing all joints with a rubber sealing compound, a small silica-gel crystal was enclosed in the instrument to absorb water-vapour. Finally the unit was immersed in warm water to test for airtightness, an essential requirement in solarimeter construction, for condensation within the dome can be extremely troublesome.

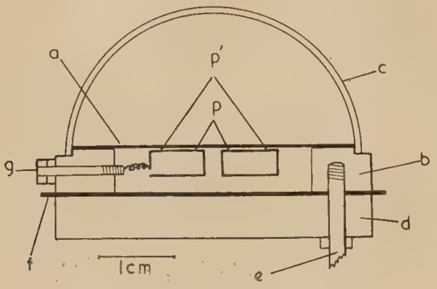


Fig. 2. Cross-section of solarimeter

PERFORMANCE

The instrument described in the previous section gave an output of 5·5 mV cal^{-1} cm^{-2} min^{-1} and the resistance was 13 Ω. A bigger unit, using a 6 cm glass dome with all other dimensions increased in proportion and 40 turns on the thermopile, gave 10·7 mV cal^{-1} cm^{-2} min^{-1} with a resistance of 24 Ω. On a portable galvanometer with Bolton Paul suspension full scale deflexions corresponded to 1·0 and 0·7 cal cm^{-2} min^{-1} for the smaller and larger instrument respectively. With suitable series resistance a similar instrument has been used to measure changes in the reflexion coefficient of field crops throughout the growing season.(11)

The response time was 20 s and the time taken for 99% response was 80 s compared with 13 s for the Kipp and 28 for the Eppley.(12)

Performance was compared with that of a Kipp solarimeter under a 2000 W lamp at the National Institute of Agricultural Engineering. Over the range 0 to 1·0 cal cm^{-2} min^{-1} the deviation from a linear relationship between the outputs of the two instruments was only ±2·5% with a systematic increase in the relative sensitivity of the instrument under test as radiation increased (Fig. 3). Adopting −5·4% for the non-linearity of the Kipp, the maximum deviation of the tested instrument from a true linear response was only 0·9%, which supports a theoretical deduction that an instrument of this type should be more linear than the Kipp Appendix). This implies that the temperature coeffi should also be less than for the Kipp, but it has not possible to verify this experimentally.

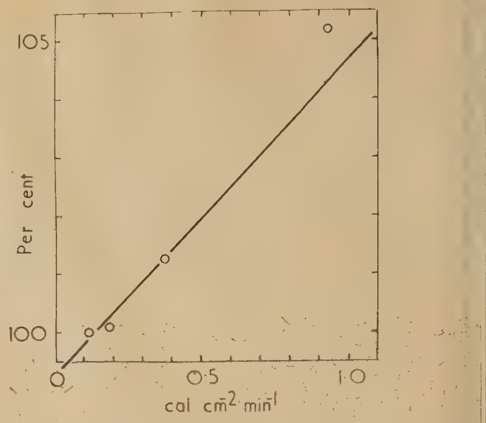


Fig. 3. Ratio of output from Rothamsted unit output from Kipp expressed as percentage of ratio 0·12 cal cm^{-2} min^{-1}

The deviation from a perfect cosine response is sho Fig. 4 and amounted to ±6% between 15° and 90° eleva The anomalously high values between 30° and 60° probably a measure of the unevenness of the glass A much better response was obtained with the 6 cm i ment for which the deviation was only ±2·5% over same range. The corresponding figure for a Kipp was f to be ±1·5%, so in this respect it appears that there is to be gained by the use of optically ground domes.

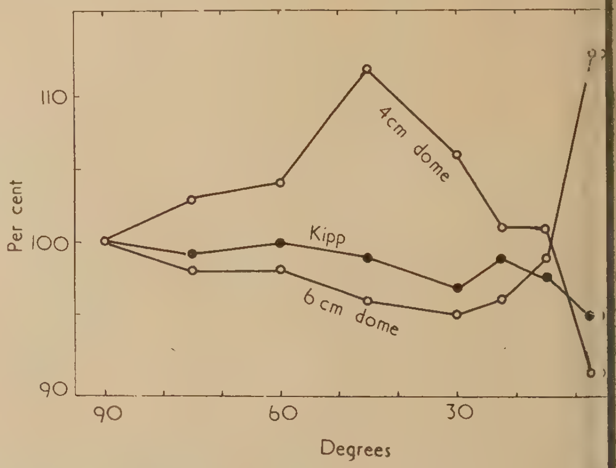
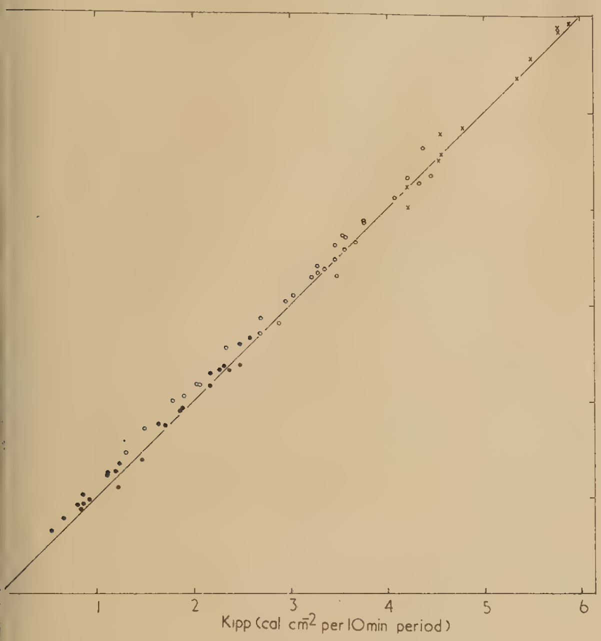


Fig. 4. Response as function of elevation of incide radiation expressed as percentage of true cosine respon

The variation in response with azimuth for radiation dent at an elevation of 30° was ±4% for the smaller sc meter, ±3% for the larger and ±1·5% for the Kipp. corresponding figures at normal incidence were ±1· ±0·4% and ±0·3%.

The response of these instruments depends more than Kipp on the angle of incident radiation. Although disadvantage outweighs any advantage from their inter and temperature coefficient, their performance is obvio acceptable for most field observations when the presenc se as well as direct light reduces the effective cosine and uth errors.

an outdoor test of performance from 17–20 February, , the outputs from a Kipp solarimeter and a 6 cm iamsted unit were recorded on two self-balancing ntiometers fitted with mechanical integration. The output from the Kipp, which runs continuously as a routine ument, had previously been shunted so that the integra- ead directly in calories per square centimetre and the ut from the Rothamsted unit was similarly shunted until l readings were obtained on the charts of the two ders. Comparison of integrator totals for 10 min ›ds then gave the values plotted in Fig. 5 which shows



g. 5. Comparison of integrated totals from Kipp and ›thamsted unit over periods of 10 min with line of unit slope

○ full sunshine; ● overcast; × sun and cloud.

the maximum divergence between the two scales was ıe order of $\pm 0 \cdot 02$ cal cm^{-2} min^{-1}. There was a systec discrepancy between the two outputs below $0 \cdot 2$ cal cm^{-2} $^{-1}$ but above this intensity there was no systematic change e relationship with varying solar angle or cloud amount. 4 cm unit gave a mean response outdoors of $5 \cdot 51$ mV ^{1} cm^{-2} min^{-1} when calibrated against the Kipp solarir with radiation up to $1 \cdot 1$ cal cm^{-2} min^{-1} and solar ıtion up to 45 deg. The maximum difference in response $\pm 0 \cdot 03$ cal cm^{-2} min^{-1} but the standard deviation for n comparisons in bright sunshine and fifteen in cloud only $\pm 0 \cdot 002$ cal cm^{-2} min^{-1}.

ACKNOWLEDGEMENTS

r. P. F. Noble and Mr. E. S. Trickett collaborated in the stages of development and much of the final construction been undertaken by Mr. G. Szeicz. Mr. L. J. Moulsley Mr. L. G. Morris provided calibration facilities at the onal Institute of Agricultural Engineering, Silsoe, and H. L. Penman has given extensive guidance in the preparation of the manuscript. To all of these, I extend grateful thanks.

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APPENDIX

The development of a rigorous theory of the instrument would be extremely tedious but a simplified treatment is given here to show how performance is related to design. The main simplification is that heat conduction in the Paxolin and the radial nature of the heat flow are ignored so that the problem can be treated as one-dimensional. A single turn of the thermopile may then be considered as a straight wire (Fig. 6) shielded from radiation beneath the Paxolin over the sections *VW* and *VZ*, attached to a perfectly absorbing black surface from *W* to *X* and to a white surface with reflectivity *r* from *X* to *Y*. The thermojunctions are at *p* and *p′* so that *pp′* is the unplated section. The temperature distribution assumed for the wire is also shown in Fig. 6.

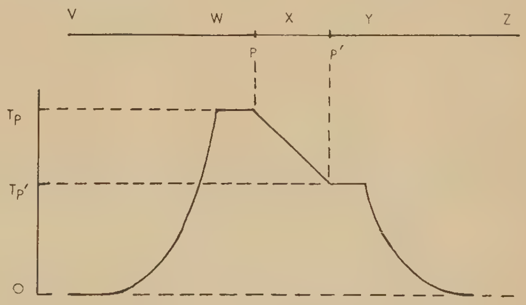

Fig. 6. Idealized temperature distribution in thermopile wire

The energy received by a single hot junction is

$$AR/n = h_1T_p + h_2T_{p'} + h_3(T_p - T_{p'}) \qquad (7)$$

and by a cold junction

$$(1 - r)AR/n = h_1T_p + h_2T_{p'} - h_3(T_p - T_{p'}) \qquad (8)$$

where h_1 = area heat transfer coefficient for convection and long-wave radiation from top and bottom surfaces of the Paxolin disk

h_2 = area heat transfer coefficient for conduction along the plated sections and thence by convection to the free air

h_3 = area heat transfer coefficient for conduction between hot and cold junctions

A = effective area of black and white surfaces assumed equal to area of black circle

n = number of thermocouples

T_p, $T_{p'}$ = excess over ambient temperature of hot and cold junctions.

Then

$$rAR/n = (T_p - T_{p'})(h_1 + h_2 + 2h_3) \qquad (9)$$

From Bener$^{(3)}$ $\qquad h_1 = 4\cdot10^{-4}\,2A/n$

while $\qquad h_3 = k'A'/l$

where k', A' are respectively the thermal conductivity and cross-sectional area of the constantan wire and l is its length.

The coefficient h_2 may be calculated from the assumption that the distribution of temperature along the wires is the same as for a wire of infinite length and is therefore given by

$$T = T_{p,p'}\,e^{-\sqrt{(\alpha)}\,x} \qquad (10)$$

where x is distance from W or Y and

$$\alpha = \pi Dh_4/(k'A' + k''A'') \qquad (11)$$

where k'' and A'' are the thermal conductivity and area of the copper deposit, D is the diameter of the plated wire and h_4 is the transfer coefficient for free convection from it. Hence

$$h_2 = (\partial T/\partial x)(k'A' + k''A'')/T$$
$$= \sqrt{\{(k'A' + k''A'')(\pi Dh_4)\}} \qquad (12)$$

Strictly, h_4 is a function of T but for the small temperature differences involved the formula quoted by Buettner$^{(13)}$ gives

$$h_4 \simeq 3\cdot10^{-5}/D$$

Defining thermal efficiency $\mathscr{E}_T$ as the ratio of $T_p - T_{p'}$ from equation (12) to the value obtained if there were no conduction along the thermocouple wires we have

$$\mathscr{E}_T = \{1 + (h_2 + 2h_3)/h_1\}^{-1} \qquad (13)$$

$$T_p - T_p' = \mathscr{E}_T rAR/h_1n = 1\cdot25\,.\,10^3\mathscr{E}_T rR \qquad (14)$$

$\mathscr{E}_T$ is shown graphically in Fig. 7 as a function of the relative cross-sections of copper and constantan.

As the constantan within the plated section of the wire can be regarded as shunting a fraction of the e.m.f. developed by the thermocouple, it can be shown that the electrical efficiency of the pile is given by

$$\mathscr{E}_E = (1 + SA'/A'')^{-1} \qquad (15)$$

where $s = 0\cdot0364$ is the ratio of electrical conductivities of constantan and copper. $\mathscr{E}_E$ has also been plotted in Fig. 7. The product $\mathscr{E}_E\mathscr{E}_T$ gives a figure of merit for the pile shows that when the copper thickness increases the dec in sensitivity produced by increased heat conductio compensated by increased efficiency of the thermocou For optimum performance the exact thickness of the de is not critical and a ratio of $A''/A' = 0\cdot2$ theoretically an optimum efficiency of about 28%.

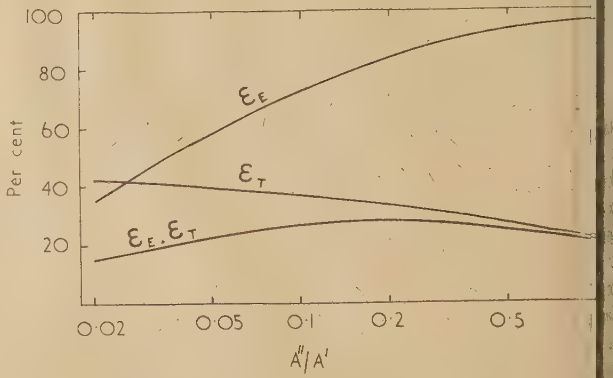

Fig. 7. Electrical efficiency $\mathscr{E}_E$, thermal efficiency and overall efficiency $\mathscr{E}_E\mathscr{E}_T$ as functions of the ratio cross-sectional areas of copper and constantan, $A''/$

This may be related to actual performance assuming when $\mathscr{E}_E = 1$ the e.m.f. of each junction is 40 μV per and that 10% of incident radiation is reflected and abso by the dome. For the instrument described on p. $A = 1\cdot9$ cm² $\quad A' = 8\cdot10^{-5}$ cm² $\quad A'' = 1\cdot6\,.\,10^{-5}$ $k' = 0\cdot054$ cal cm^{-1} s^{-1} per deg C $\quad k'' = 0\cdot92$ cal c s^{-1} per deg C $\quad l = 0\cdot55$ cm $\quad n = 27$.

Then $T_p - T_{p'} = 6\cdot9°$ C and $E/R = 5\cdot72r$ mV cal^{-1} c min^{-1} compared with an observed value of 5·5 cal c min^{-1}. The reflectivity of the white surface is prob between $r = 0\cdot7$ and $r = 0\cdot8$ so the theory under-esti sensitivity: but agreement is sufficiently good to justif of the theory in predicting how performance will change design. For example, it can be shown that output can substantially increased for a given number of couples increasing the size of the black circle; and that by shorte the length of the unplated section of the wire an instru of lower resistance can be obtained with little sacrific sensitivity.

Non-linearity and temperature coefficient can be calcul by comparing equations (1), (2) and (9), from which

$$\Sigma h_i = (h_1 + h_2 + 2h_3)n/rA$$
$$= 2\cdot5\,.\,10^{-3}$$

by experiment.

The temperature dependence of the transfer coefficients conduction along the wires is very much less than for vection and long-wave radiation, so

$$\Sigma\partial h_i/\partial T \simeq (\partial h_1/\partial T)(n/rA) = 5\cdot4\,.\,10^{-6}$$

from Bener (*loc. cit.*, p. 226).

For a copper-constantan junction

$a = 40\,\mu$V per deg C, and $b = 0\cdot04\,\mu$V per (deg C)^2

Then from equations (4) and (5) non-linearity is —0 cal^{-1} cm^{-2} min^{-1} and the temperature coefficien —0·12% per deg C.

nproved equipment for the measurement of interfacial potentials

y C. D. Kinloch, A.M.I.E.E., and A. I. McMullen, Ph.D.(Cantab), The British Rubber Producers' Research Association, Welwyn Garden City, Herts.

[*Paper received* 16 *March*, 1959]

A modified vibrating-electrode apparatus designed for the reliable measurement of air-water and oil-water adsorption potentials is described. The equipment is capable, under the best conditions, of measuring potential differences of 0·2 mV at the air-water surface and of 0·5 mV at the oil-water interface. The surface potentials of small quantities (0·1 ml.) of aqueous solutions may be measured rapidly to a lesser degree of accuracy.

eterminations of small interfacial potentials there are main sources of error. First, there may be insufficient ol over the cleanliness of the surface in question, the nce of impurities at the interface giving erroneous ngs. Second, the nature of the system being measured be such as to preclude accurate readings; thus an inter- not in equilibrium with both phases may give rise to sistent or time-dependent potentials. Third, control of tability characteristics of the electronic and mechanical ment employed may be inadequate for the accuracy d.

is paper is concerned with satisfying a need for uately stabilized measuring equipment, based on the gement described by Davies.(1) The principle under- the method is given by Yamins and Zisman.(2) It is ved that the improvements achieved in this apparatus from the use of: (i) a precision vibrating unit controlled single-frequency oscillator, (ii) a carefully designed ifier incorporating an effective filter system for the nation of spurious frequencies, (iii) a detector stage ntly screened from electrical interference and isolated mechanical and sonic vibrations. The equipment is rated diagrammatically in Fig. 1.

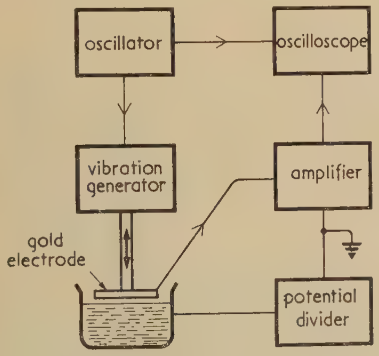

Fig. 1. Block schematic diagram of apparatus

OSCILLATOR

e circuit of the oscillator is shown in Fig. 2. It is ded to work at a single frequency of 250 c/s and it is fore possible to use a simple single-valve resistance- citance oscillator circuit with two output stages feeding ibration generator and providing the reference signal to athode-ray tube display.

VIBRATION GENERATOR

standard unit, type V47 (by Goodmans Industries Ltd.), been used. This is a compact unit with permanent- et field and a driving-coil impedance of 3 Ω. A gold (or gold-plated brass) electrode is carried at the end of an insulating rod attached to the driving core. The body of the vibration generator is held on a bracket provided with a screw-motion for adjusting the position of the electrode relative to the surface under test. This bracket is mounted quite separately from the screened box which houses the electrode and measuring cell so that mechanical vibrations are not set up in the box. The arrangement is illustrated in Fig. 4.

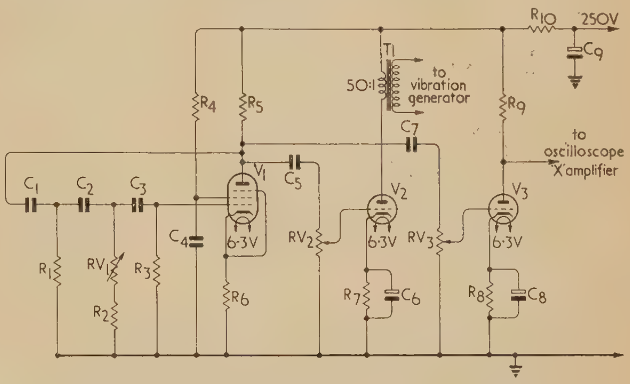

Fig. 2. Circuit diagram of 250 c/s oscillator

R_1 = 1 MΩ
R_2 = 330 kΩ
R_3 = 1 MΩ
R_4 = 680 kΩ
R_5 = 220 kΩ
R_6 = 1 kΩ
R_7 = 3·3 kΩ
R_8 = 3·3 kΩ
R_9 = 100 kΩ
R_{10} = 10 kΩ

RV_1 = 1 MΩ
RV_2 = 1 MΩ
RV_3 = 1 MΩ

C_1 = 250 pF
C_2 = 250 pF
C_3 = 250 pF
C_4 = 0·1 μF

C_5 = 100 pF
C_6 = 20 μF
C_7 = 100 pF
C_8 = 20 μF
C_9 = 8 μF

V_1 = 6BR7
V_2 = 6C4
V_3 = 6C4

AMPLIFIER AND WAVE-FILTER CIRCUIT

This circuit is shown in Fig. 3. The signal derived from the vibrating electrode is detected by means of an amplifier tuned to the oscillator frequency of 250 c/s. To obtain the greatest sensitivity, the input resistance of the amplifier must be as high as possible and a value of 50 MΩ has been used. A high-stability carbon resistor is suitable for R_1, provided that one with low noise level can be selected by trial. For this input resistance to be effective at 250 c/s, the shunt capacitance of the input circuit must be kept as low as possible. Therefore the input stage is a cathode-follower arrangement mounted in a screening can immediately adjacent to the box surrounding the electrode and test surface. A bare flexible lead connects the electrode to the grid of the cathode follower, and stringent precautions are taken to avoid mechanical vibrations reaching this stage, the input resistor being particularly sensitive to vibration.

The cathode-follower output is at low impedance, and the remaining stages of the amplifier can be at any convenient distance from the input stage. Here the amplifier is contained in the same case as the oscillator.

Tuning is effected on two of the three amplifying stages by means of feedback networks consisting of parallel-T filters tuned to reject signals at 250 c/s. By this means, all unwanted frequencies are fed back negatively and are largely suppressed; a degree of gain control is obtained from two preset variable resistors.

diameter, and they require respectively 0·75 ml., 5·0 ml. 35 ml. of solution to create a convex meniscus such when cleaned by suction, the surface reaches the level o wall.

For experiments where the aqueous solute is inj underneath an insoluble film, the largest cell is used and solute is mixed by means of a rotary magnetic stirrer dri a thin glass-encased metal wire immersed in the solution

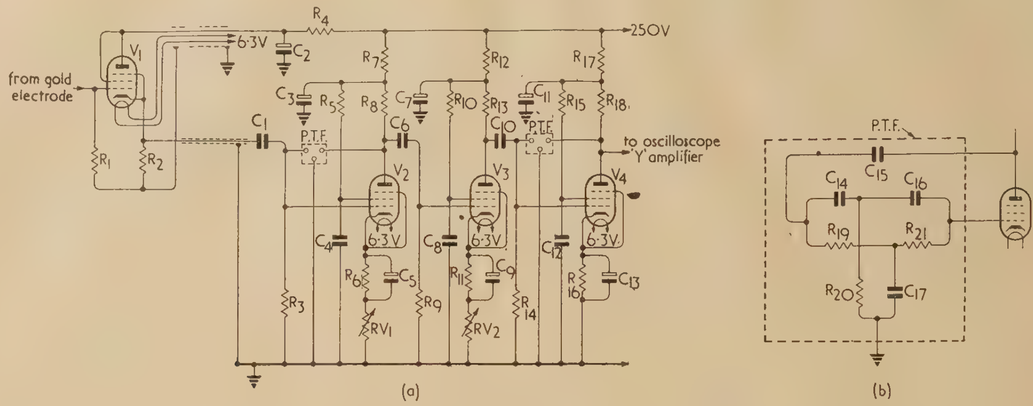
from gold electrode
6·3V
250V
to oscilloscope 'Y' amplifier
P.T.F.
V_1 V_2 V_3 V_4
R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10} R_{11} R_{12} R_{13} R_{14} R_{15} R_{16} R_{17} R_{18} R_{19} R_{20} R_{21}
RV_1 RV_2
C_1 C_2 C_3 C_4 C_5 C_6 C_7 C_8 C_9 C_{10} C_{11} C_{12} C_{13} C_{14} C_{15} C_{16} C_{17}
(a)
(b)

Fig. 3. (*a*) Circuit diagram of amplifier tuned to 250 c/s. (*b*) Parallel-T filter (P.T.F.)

R_1 = 50 MΩ (h.s. carbon)
R_2 = 100 kΩ
R_3 = 680 kΩ
R_4 = 10 kΩ
R_5 = 1 MΩ
R_6 = 2·2 kΩ
R_7 = 100 kΩ
R_8 = 220 kΩ
R_9 = 680 kΩ
R_{10} = 1 MΩ
R_{11} = 2·2 kΩ
R_{12} = 100 kΩ
R_{13} = 220 kΩ
R_{14} = 680 kΩ
R_{15} = 1 MΩ
R_{16} = 2·2 kΩ
R_{17} = 100 kΩ
R_{18} = 220 kΩ
R_{19} = 600 kΩ
R_{20} = 300 kΩ
R_{21} = 600 kΩ

RV_1 = 20 kΩ
RV_2 = 20 kΩ
C_1 = 0·01 μF
C_2 = 8 μF
C_3 = 8 μF
C_4 = 0·1 μF
C_5 = 20 μF
C_6 = 0·01 μF
C_7 = 8 μF
C_8 = 0·1 μF
C_9 = 20 μF
C_{10} = 0·01 μF
C_{11} = 8 μF
C_{12} = 0·1 μF
C_{13} = 20 μF
C_{14} = 1000 pF
C_{15} = 2000 pF
C_{16} = 1000 pF
C_{17} = 2000 pF

V_1 = 6BS7
V_2 = 6BS7
V_3 = 6BR7
V_4 = 6BR7

DISPLAY AND SENSITIVITY ADJUSTMENT

The amplifier signal from the vibrating electrode is applied to the "Y" plates of a cathode-ray oscilloscope, while the reference signal derived from the 250 c/s oscillator is applied to the "X" plates, so that an ellipse is formed. The usual null method of measurement is employed, whereby the interface potential is opposed by the voltage from a potentiometer. When the system is balanced, the cathode-ray tube display changes from an ellipse to a horizontal line, and the value of the interface potential is read from the potentiometer.

To reproduce the electrode-interface separation distance, and thus obtain constant sensitivity throughout a series of experiments, it is only necessary to set the electrode at an arbitrary distance and proceed as follows: Roughly balance the potential, offset the balance by a given amount using the potentiometer and alter the electrode height until the off-balance ellipse occupies a given width of the display grid. The procedure is repeated several times until, by this successive-approximation technique, a final accurate positioning of the electrode is made. The magnitude of off-balance potential applied, the spread of the ellipse on the display, and the amplification required to achieve the required sensitivity are found by trial and error because they depend on the amplification characteristics of the complete equipment.

THE CELL AND ELECTRODE SYSTEM

This portion of the apparatus is shown in Fig. 4. One of three shallow circular Pyrex cells is commonly used, depending on the accuracy required, the amount of solution available and whether or not injection procedures are to be employed. The dimensions are 4 mm deep and 15 mm diameter; 8 mm deep and 30 mm diameter; and 8 mm deep and 75 mm

long side-arm tube, open at either end, connects the l aqueous solution to a 10^{-3}M–KCl/calomel wick elect outside the screened box.

Exchangeable circular gold-disk electrodes of 1 or diameter and 0·5 mm thick are used with the approp

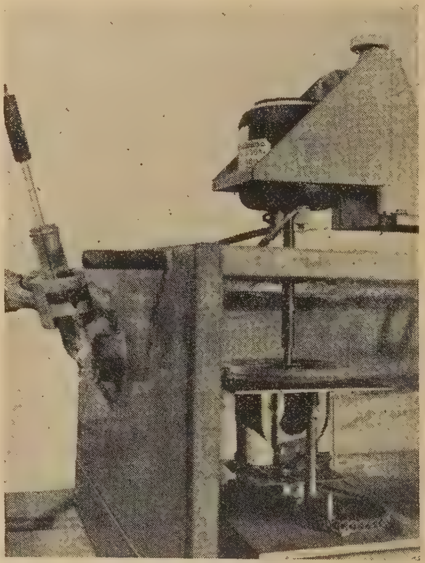

Fig. 4. Vibration generator, electrodes and cell

cell (the smaller the vibrating-electrode area, the lower sensitivity). All these cells may be used for measuring surface and interface potentials. For interface potent the aqueous solution fills only the lower half of the cell, redistilled equilibrated oil being poured on to the clea trate surface and the gold electrode being then immersed e oil layer. For measurements of surface potential with ition in area of insoluble films, the Langmuir trough boom are used in place of the cell, and a rectangular -plated electrode of dimensions 5 × 50 × 0·5 mm is loyed. This is shown in Fig. 5.

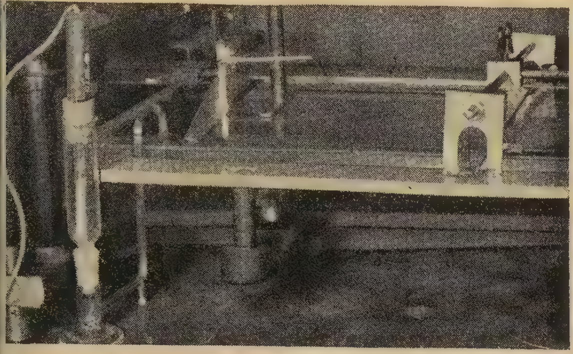

Fig. 5. Langmuir trough with rectangular electrode

or rapid semi-quantitative air/water measurements on 1 (0·1 ml.) volumes, a special multiple "cell" has been sed. Twelve etched disks or slight depressions, 1 cm in neter, are distributed radially, about 3 cm from the re, on a circular glass or plastic plate 10 cm in diameter . 6). The solutions to be examined are loaded on to twelve positions and each is separately connected to a ral buffer-impregnated filter-paper pad by short lengths hread (previously washed in the appropriate substrate er). Flooding of the threads by this reservoir buffer or he sample solutions is prevented by lightly coating the ral section of the glass plate with silicone grease. The k of the calomel electrode is then placed in contact with buffer pad and all sample solutions are cleaned by surface ion.

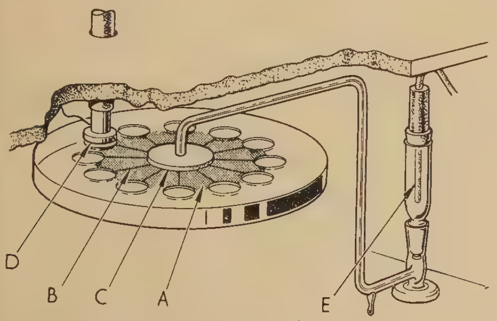

Fig. 6. Semi-quantitative multiple cell

, silicone grease; *B*, conductor thread; *C*, filter-pad buffer reservoir; *D*, 1 cm electrode; *E*, calomel electrode.

he carrier disk is then rotated so that each solution is itioned in turn under the vibrating electrode. A series of lve solutions can be measured in a few minutes, sucked the positions rinsed with substrate buffer, fresh solutions lied and the procedure repeated. This is particularly ful as a rapid method where errors of several millivolts not important. For accurate investigations and, in particular, for those concerned with oil-water interface measurements, the 35 ml. cell and 2 cm electrode are desirable.

PERFORMANCE

Reproducibility with this equipment appears to depend largely on the system examined. Thus potentials of metal/air surfaces are extremely constant and, because of the complete rigidity of the system, it is possible to position the vibrating electrode so close to the metal (less than 0·5 mm away) that extreme sensitivity is obtained. (Distortion of the sine-wave signal occurs, however, at very small separation.) At these close distances, a reproducibility of about 0·1 mV is attainable with the potentiometer employed. Even with insoluble spread films such as those obtained with fatty acids and with protein on non-solvent substrates at low areas per molecule, a sensitivity of 0·2 mV and a reproducibility of 0·5 mV may be quoted. The table shows that good agreement with other workers is obtained using the 35 ml. cell.

Comparison with the polonium electrode at the air-water interface

Stearic acid at pH 2·0

This work	Area/molecule (Å^2)	25·6	22·4	20·8
	V (mV)	376	387	400
Schulman and Marsden(3)	Area/molecule (Å^2)	25·0	22·7	21·1
	V (mV)	373	387	395
Cockbain(4)	Area/molecule (Å^2)	25·6	22·7	21·1
	V (mV)	381	396	402

It is not possible to obtain such rigid films at the oil-water interface and here, because of changes in the film itself and of the difficulty in obtaining such a small separation between electrode and interface, the sensitivity is lowered to 0·5 mV and the same reproducibility is only obtained in certain cases where complete insolubility of the film in both phases exists. This equipment has been employed successfully in measurements of the adsorption potentials of monolayers of soluble ionized detergents,(5) insoluble interfacial films of polymeric ethers,(6) and solutions of protein and soap-protein mixtures.(7)

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Electron-optical design of an X-ray micro-analyser

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The electron-optical design of an X-ray micro-analyser is considered in some detail with a view to establishing the best design. The electron-optical system has to fulfil conditions not normally encountered—for example, in the electron microscope where the optimum design has been extensively studied. A system is described that has proved suitable for a practical X-ray micro-analyser using magnetic lenses of axial symmetry. Brief reference is made to possible future developments such as the introduction of corrected lenses.

In the X-ray micro-analyser, an instrument first described by Castaing and Guinier(1) and subsequently developed by many other workers,(2–5) a finely focused electron beam or "probe", one micron in diameter, is directed on to a chosen part of a target and the resulting characteristic X-rays are analysed by means of a suitable spectrometer. The successful application of this technique to X-ray spectro-chemical analysis of selected micro-areas has largely been made possible by a better understanding of the properties of electron sources and lenses gained from considerable research carried out in connexion with the electron microscope.

Although the electron-optical requirements of X-ray micro-analysis are similar to those of electron microscopy, there are important differences, notably in the way in which the spherical aberration of the lenses affects the resolution of the system and secondly in the criterion for resolution itself. Archard(6) has recently discussed the necessary modification of the spherical-aberration coefficient for imaging conditions not usually encountered in the electron microscope but frequently occurring in electron-probe systems. Similar questions also arise in the design of fine focus X-ray tubes with spot sizes less than about 5 microns.

Recent developments in electron sources and in methods of correcting lens aberrations may provide a means of improving the sensitivity and resolving power of electron probes for micro-analysis. It is the purpose of this paper to determine the best electron-optical design for an X-ray micro-analyser using a conventional imaging system and to point out where improvements are likely to occur in the near future.

The design principles are illustrated by reference to an X-ray micro-analyser which has been designed and developed in this laboratory. This instrument has now been in operational use for several years.

BASIC PARAMETERS

One of the difficulties in the design of an electron-probe system is to concentrate a sufficient current into the probe. This current is several orders of magnitude less than that employed in conventional X-ray tubes. Target heating may be ignored under these conditions. The limit is set chiefly by the spherical aberration of the final demagnifying lens and the current density per unit solid angle (Richtstrahlwert) of the electron gun. The distribution of electrons in a focused spot is Gaussian in character. If the half-width of the distribution is d, and the spherical aberration coefficient of the lens is C_s, then the effect of spherical aberration is to broaden this distribution. The diameter of the minimum disk of confusion d_s caused by spherical aberration is given by:

$$d_s = \tfrac{1}{2}C_s\alpha^3. \qquad (1)$$

This should not exceed the spot size d. Hence the semi-angle of the limiting aperture should not exceed a valu given by:

$$\alpha_m = \left(\frac{2d}{C_s}\right)^{1/3}.$$

The maximum current density in the probe is given by:

$$\rho = \pi\alpha_m^2\beta,$$

where β is the current density per unit solid angle at cathode, leading to a total current I in the probe given

$$I = \frac{\pi^2 d^{8/3}}{(4C_s)^{2/3}}\beta.$$

Equation (4) shows that the probe current decre rapidly with probe size; halving the probe diameter, example, leads to a six-fold reduction of current. The cu varies linearly with the quantity β and inversely as the thirds power of the spherical aberration coefficient.

Typical values used in a micro-analyser are $C_s = 2\cdot5$ $d = 0\cdot5 \times 10^{-4}$ cm and $\beta = 50\,000$ A/cm² per unit angle at 25 kV, and insertion of these in equation (4) g I to be approximately $0\cdot4 \times 10^{-6}$ A for a half-micron pr

LENS DESIGN

The only aberrations of the electron-optical system of significance are those that occur in the final demagni lens. This lens must not only have low spherical aberra but its focal point must be outside the lens shell to en large specimens to be examined, and to facilitate the pas of the emergent X-ray beam into the spectrometer. If *working distance*(7) between the focal point F and the in of adjacent poleface P (see Fig. 1) is denoted by l and bore and air-gap spacing by D and S respectively, then lens should be designed to make l/C_s a maximum. Fig based on Liebmann's data(8) shows that, for a given

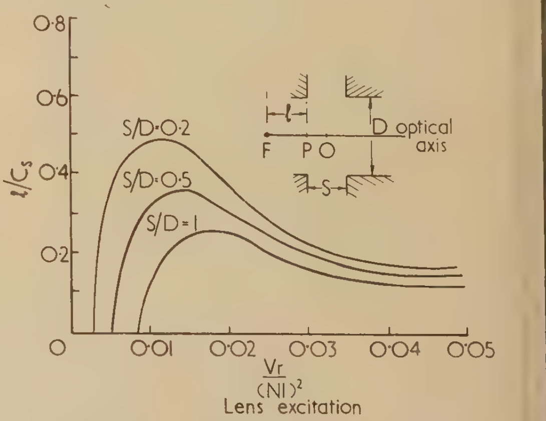
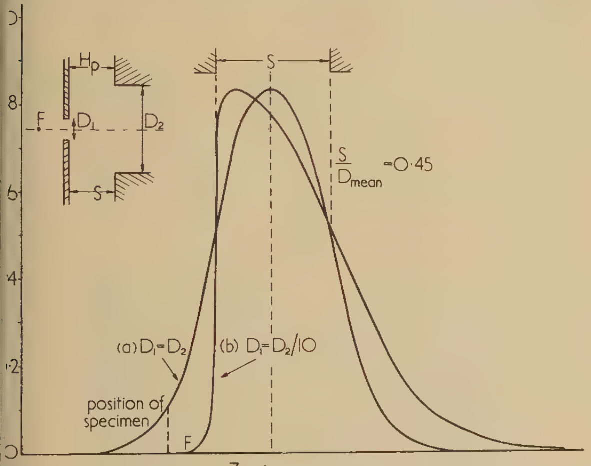


Fig. 1. Variation of l/C_s with lens geometry an excitation

ıetry, l/C_s goes through a maximum as the parameter $VI)^2$ is varied, where V_r is the accelerating voltage and ıe number of ampere-turns. This maximum becomes favourable as the ratio S/D is reduced. In practice, cannot be reduced indefinitely because of magnetic ation of the iron circuit and a value somewhere between ınd 0·5 is a favourable compromise. This leads to a of $V_r/(NI)^2$ between 0·01 and 0·015 corresponding to to 1500 ampere-turns respectively at 30 kV. The ıum excitation is consequently much less than that red in a lens for the electron microscope.(9) To use a er excitation than the optimum would cause a serious ction in working distance without a corresponding ction of spherical aberration. On the other hand, a ction of excitation would lead to a sharp rise in spherical ation without a great gain in working distance. Values S/D and $V_r/(NI)^2$ having been fixed, the actual values and D can be found directly from Liebmann's data.(8)

THE MAGNETIC FIELD OF THE SPECIMEN

further technical requirement in the micro-analyser is the magnetic field strength at the specimen should be as as possible in order that a ferro-magnetic specimen ld not disturb the lens field. Unfortunately the use of all value of S/D and lens bores of equal diameter leads gh values of field strength on the axis in the region of pecimen. This is shown in curve (*a*) of Fig. 2 which



g. 2. Axial field distributions in symmetrical and asymmetrical lenses

/s the axial field distribution according to Liebmann(10) lens with equal bores and a value of S/D of 0·45. The strength in the region of the focal point is as high as tenth of that in the air gap. By a reduction of the ıeter D_1 of the lens bore nearest the specimen and an ase of the other bore D_2, a considerable reduction of field at the specimen is possible, as shown in curve (*b*) ig. 2. Provided that the mean diameter $(D_1 + D_2)/2$ of lens is unaltered by this operation, Liebmann's cal- tions show that the focal properties of the lens, and in icular the spherical aberration coefficient, are hardly ted. One may therefore conclude that the working ınce l in the most favourable arrangement will be approxi- ely one-third of the spherical aberration coefficient. It ıe that a slight improvement is possible, but only at the nse of a greatly increased magnetic field at the specimen.

UNIT-MAGNIFICATION LENSES

In principle, the working distance of a lens can be doubled by using it at unit magnification. For a thin lens, the working distance under these conditions is equal to twice the focal length; that is, double that at infinite conjugates. A possible system of this type is shown in Fig. 3. A conventional objective lens of short focal length (for example, 2·0 mm) and comparable value of C_s is used to form a fine probe which is inaccessible because it is formed within the lens. A second lens working at unit magnification is then used to produce a focus outside the system. Unfortunately, the spherical-aberration coefficient increases when a lens is used at unit magnification. Archard(11) has evaluated this increase for various values of lens strength. He finds that, for moderately strong lenses, the increase in C_s is about 60% for a unit-magnification lens compared with the same lens working at infinite conjugates and having the same working distance.

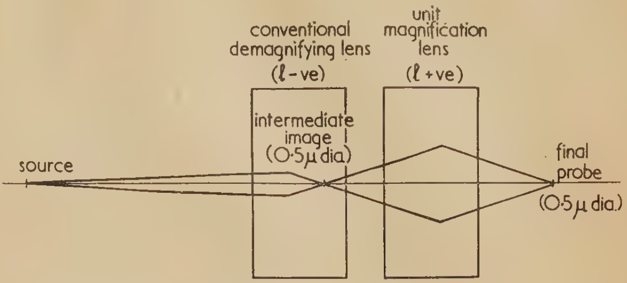


Fig. 3. Use of unit-magnification lens to obtain positive working distance

Although the unit-magnification system is slightly inferior in performance to the one used at infinite conjugates, it is probably the most convenient system to use, for example, when adapting an existing electron microscope for X-ray micro-analysis.

STABILITY REQUIREMENTS

If the accelerating voltage changes, the probe size will also change. However, the probe size is not directly related to resolution because in practice the probe size would be made somewhat smaller than the least-resolved distance as set by electron scattering and diffusion in the specimen. Under these conditions the required voltage stability dV/V is given approximately by:

$$\frac{dV}{V} < \frac{d^{2/3}(C_s/2)^{1/3}}{2f}, \tag{5}$$

where dV/V is the fractional change in accelerating voltage and f is the focal length of the final lens. For example, if $d = 0{\cdot}5 \times 10^{-4}$ cm and $C_s = f = 2{\cdot}5$ cm, then

$$dV/V < 3 \times 10^{-4}.$$

The stability requirements are not difficult to fulfil, being comparable with those of the projector lenses in an electron microscope.

CONSTRUCTION

The construction of a suitable electron-optical system based on the foregoing principles is shown in Fig. 4. An electron gun (1) serves as a source of electrons. The performance of the gun can be checked by inserting a Faraday cage (4) into the beam and measuring the current passing through a known aperture. From this, the β-value of the gun can be calculated readily and maintained close to the theoretical value.(12) The demagnification of the source takes place in two stages. The first stage consists of a magnetic lens (5) of variable focal length; its main function is to control the final spot size over a range 0·3–5 μ diameter. The final demagnifying lens (7) is of the asymmetrical type having a large bore on the gun side (6·0 cm diameter) and a small bore (0·6 cm) to reduce the field at the specimen (12). Its focal length is 2·8 cm, with $C_s = 3{\cdot}0$ cm. The lenses are fixed rigidly to each other, the only adjustments being the gun traversing controls (2) and, underneath these, the adjustable anode of the gun which is used to tilt the beam parallel to the optical axis.

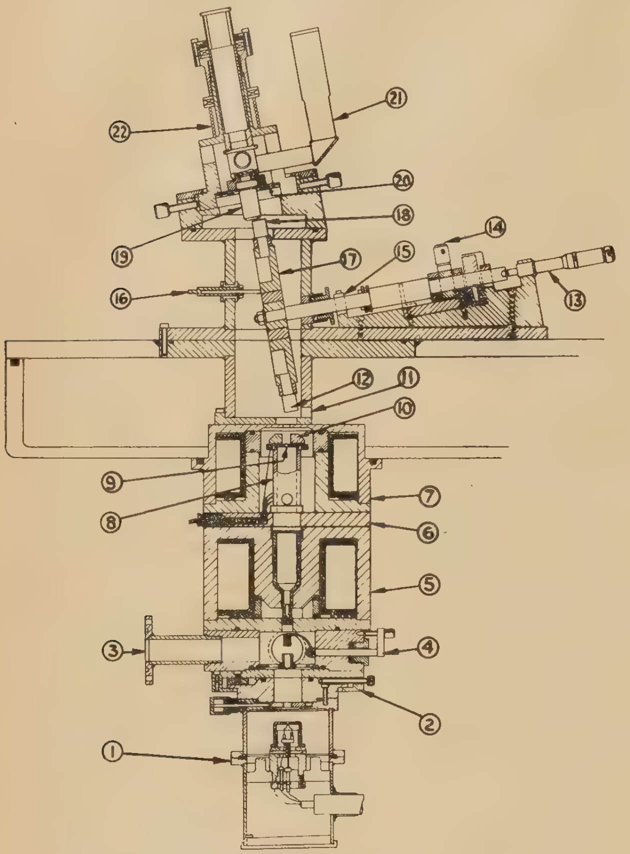


Fig. 4. General arrangement of the optical and electron-optical system

The limiting aperture (9) of the final lens is mounted in a cone that can be removed from the instrument for cleaning by inserting a suitable tool through the small bore. Above the aperture are two pairs of electrostatic deflector plates (10), mounted on a tube (8). These enable the probe to be moved across the specimen by applying a deflecting voltage between opposite plates; a deflexion of one micron per volt is obtained at an accelerating voltage of 30 kV. The connexions to the deflectors are taken through a vacuum seal in the supporting plate (6). The deflector system is also used as part of an electron scanning system(13) in the manner described by Cosslett and Duncumb.(14) The present design differs from previous ones in that the scanning is electrostatic and takes place *after* the lens aperture, which results in a simpler system. It should also be mentioned that the apparatus can
be used without modification as a fine-focus X-ray t
target-changing is particularly simple. If the speci
manipulating-stage is removed and a thin target placed
the small bore of the final lens, the probe being refoc
on to it, X-ray projection-microscope images can be obta
with a resolution of about a micron. Exposure times w
however, be about three times as long as those neede
instruments designed specifically for this purpose.(15, 16)

X-RAY SPECTROMETER

The specimen (12) is mounted on a drum (17) and
X-ray beam, which is excited by the electron probe, p
through a thin "Mylar" window (6·4 μ) into the X
spectrometer, which is of the conventional Johansso
bent-crystal type. A range of elements from uraniu
magnesium can be covered. The spectrometer is evacu
when working in the soft X-ray region to avoid X
absorption. A diffraction grating spectrometer is
incorporated for experiments in the 10–44 Å rang
wavelengths.

OPTICAL-VIEWING SYSTEM

The specimen is positioned under the probe by mea
a metallurgical microscope (22) of standard design, bu
objective lens (19) of which operates under vacuum to
the highest powers to be used. The vacuum seal is mad
a rubber diaphragm (20) and a plane-glass window fitte
the vertical illuminator. The objective lens can readi
changed to suit the specimen detail under investigation.
specimen and drum (17) are positioned under the cross-
of the microscope by means of a radial (14) and an axial
micrometer. By the operation of a lever which is atta
to the shaft (15), the specimen drum is turned through 1
bringing the chosen part of the specimen under the elec
probe. The optical microscope is initially alined by pla
a copper target under the probe and building up a
tamination spot as shown in Fig. 5. When the dru
rotated the spot will, in general, appear in the field of
some distance away from the intersection of the cross-w
The position of the optical microscope is then altered
means of traversing screws until the spot appears under
cross-wires. This arrangement was first suggested by M
Haine and has the advantage that the optical and the elect
optical systems are separated from each other, thus allo
the optimum design for each. Care has to be taken, howe
in the accuracy of the rotation of the shaft. In the pre

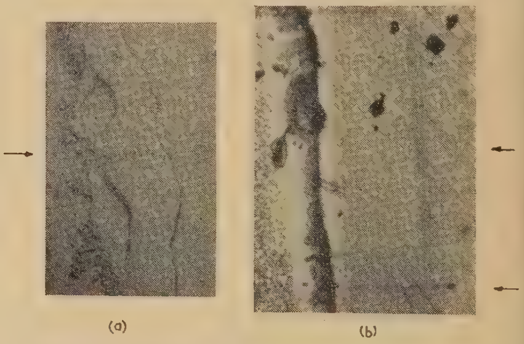

(a) (b)

Fig. 5. Contamination spots formed on a target
(*a*) Fairly coarse (3 μ) spots on Cu–Al compound.
(*b*) Row of fine spots ($<1\ \mu$) on nickel with square sca
130 μ × 130 μ above.

gement, the shaft is mounted in hardened and ground cks to ensure satisfactory operation. Small movements v microns on each side of an inclusion, for example) of robe can be made electrically by making use of the cting plates.

MEASUREMENT OF PROBE SIZE

o methods of measuring probe size have been found 1 in practice. The first method makes use of the con- ation figure that appears on the specimen when an on beam strikes its surface in the presence of hydro- n vapour. To make quantitative use of the contamina- spot, certain factors must be borne in mind. Ennos[18] d that the thickness of this contaminating layer (of n) is proportional to the electron density at the surface, emperature being kept constant. If the current density bution in the probe is assumed to be Gaussian, the nt density at a distance r from the centre of the probe en by:

$$\rho = \rho_m \exp(-kr^2) \qquad (6)$$

e ρ_m is the maximum current density in the probe and a constant. The thickness h of the layer at any point is ı by:

$$h = c\rho \qquad (7)$$

e c is a constant for a given surface temperature and t ıe time of irradiation. The contamination will first ar in the centre of the spot where the current density is est. If h_0 is the minimum observable thickness (h_0 is oximately 50 Å), then the spot will first appear at a $t_0(=h_0/c\rho)$ after the start of irradiation. Combination ıuations (6) and (7) gives the radius of the just-visible at time t to be:

$$r = r_{1/2}\left\{\frac{ln(t/t_0)}{ln2}\right\}^{1/2}, \qquad (8)$$

e $r_{1/2}$ is the radius at "half-height" of the electron dis- tion. The time t_0 will vary with surface temperature the vacuum conditions, large values of t_0 being associated high temperatures and good vacuum conditions.

ıuation (6) shows that, after a time $2t_0$, the diameter of pot will be equal to the half-width of the probe. Fig. 6 vs how the observed contamination spot diameter ases with time, measured in units of t_0. The observed es are consistent with the curve calculated from equation shown in Fig. 6 as a full line. By observation of the amination spot at 400 times for slightly different lens ents it is possible (*a*) to check that the probe is focused, (*b*) to estimate the probe size and electron distribution ıtitatively and in a manner that is independent of the ace or vacuum conditions.

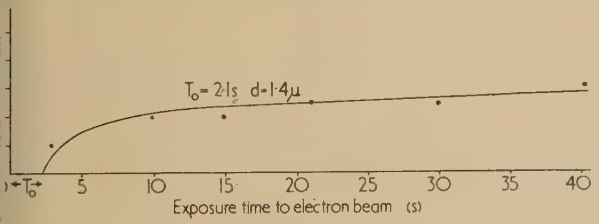


Fig. 6. Growth of contamination spot with time

—— calculated from Gaussian distribution.
● experimental observations.

CONTROL OF CONTAMINATION RATE

It is useful in a micro-analyser to be able to control the contamination rate. Casting and Descamps[19] described an arrangement in which an air jet directed at the specimen caused a reduction of contamination. Recently, Heide[20] has shown that it is the oxygen that causes decontamination. It appears that, in most demountable systems, the *contamination* mechanism caused by hydrocarbon vapour is predominant. By increasing the oxygen pressure, the *decontamination* mechanism can be made to predominate. This can be carried out easily in a micro-analyser by inserting a diaphragm between the specimen chamber and lens system to cut down the pumping speed in the neighbourhood of the specimen and thereby increasing the oxygen pressure locally without substantially affecting the total mean free path of the electrons from gun to specimen. A suitable system is shown in Fig. 7. The hydrocarbon vapour pressure can also be reduced by the use of liquid-air traps placed near the specimen as described in the literature.[21–23]

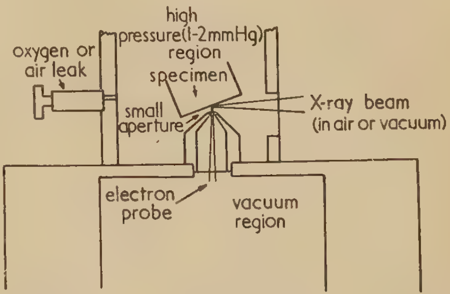


Fig. 7. Control of contamination rate by increasing the oxygen/hydrocarbon vapour-pressure ratio near the specimen

OVERALL RESOLUTION

The second method of estimating probe size makes use of the scanning system. The probe is scanned across a wedge-shaped gap and the cathode-ray tube image is formed by the appropriate $K\alpha$-radiation. Fig. 8 shows such an electron-scanning picture taken with the cathode-ray tube modulated by the copper-$K\alpha$ signal from the spectrometer. The specimen consists of two copper-rich bismuth crystals (bright areas) with a wedge-like gap of bismuth (dark area) between them. The gap is, in fact, about a third of a micron at its narrowest point. Although this is not clearly resolved,

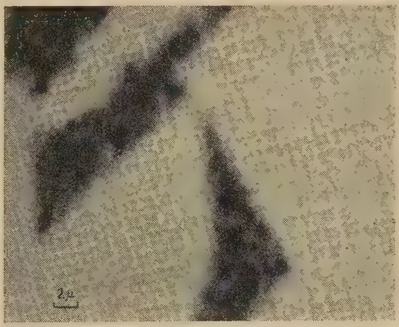


Fig. 8. Electron-scanning picture (×3500) of a wedge-like gap between two copper-bismuth crystals to determine probe size. Resolution better than 1 μ

there is a noticeable change in contrast, and the resolution may be estimated as a micron or better. Because this is the estimated limit of resolution resulting from electron diffusion in bismuth at the accelerating voltage employed (30 kV), the probe must be smaller than this.

CORRECTION OF ASTIGMATISM

It is well known(24, 25) that if the bore of an electron lens is slightly elliptical, astigmatism will result, even on the axis. The minimum diameter d_A of the probe, as limited by astigmatism, is given by:

$$d_A = Z_a \alpha \tag{9}$$

where Z_a is the axial distance between the line foci. Clearly d_A should be less than the probe diameter d. Thus, from equation (2):

$$Z_a < \left(\frac{d^2 C_s}{2}\right)^{1/3}. \tag{10}$$

With typical values of $d\,(0{\cdot}5 \times 10^{-4}\ \text{cm})$ and $C_s\,(2{\cdot}5\ \text{cm})$ then Z_a is less than 10 μ, which corresponds to a difference in maximum and minimum radii of about 2 μ in the lens bore.(26) By good design and careful machining a value of Z_a of 1–2 μ can be obtained without great difficulty in a magnetic lens, so that astigmatism should not arise from this cause. On the other hand, prolonged operation may cause contamination of apertures and walls of the instrument, leading eventually to a noticeable astigmatism of the probe. This can be corrected without difficulty, thus avoiding the necessity of dismantling the instrument for cleaning.

The correcting system adopted is shown schematically in Fig. 9 and consists of two electrostatic quadrupoles. The design is based on that first published by Bertein(24) and applied independently in a modified form to the electron microscope by Rang.(27) In the present design, eight insulated metal cylinders are arranged round the optical axis; opposite pairs are connected together internally and the four leads from the pairs are brought out of the vacuum through a suitable seal. The corrector is mounted under the objective aperture and deflector plates. Fig. 10 shows a photograph of the complete assembly. The control circuit is also shown in Fig. 9. This type of corrector produces two astigmatic components A_x and A_y at right-angles to each other, the magnitudes of which are proportional to the voltages V_x and V_y impressed on the plates by the potentiometers P_x and P_y. These are connected to a d.c. supply of 100 V, one terminal of which may be earthed and the other either positive or negative, as convenient—for example, either a nega line or the h.t. supply of a lens could be used. This is n possible by the use of eight electrodes instead of minimum of four; the four-electrode system is geometri asymmetrical and suffers from the non-cancelling effec electrode contamination. Change-over switches S_1 an serve to reverse the sign of the correcting field applie accordance with the direction of the astigmatism to corrected. To operate the corrector, one potentiomet set to zero and the astigmatism reduced to a minimu the other. The first potentiometer is then adjusted to re the remaining astigmatism to negligible proportions. correction can be checked conveniently by observing contamination spot on a copper target.

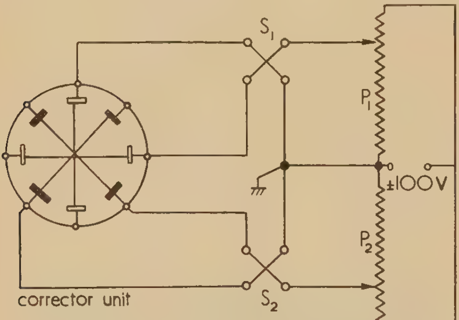


Fig. 9. Schematic arrangement of eight-pole astigmatism-corrector system consisting of two quadrupoles displaced by 45° from each other

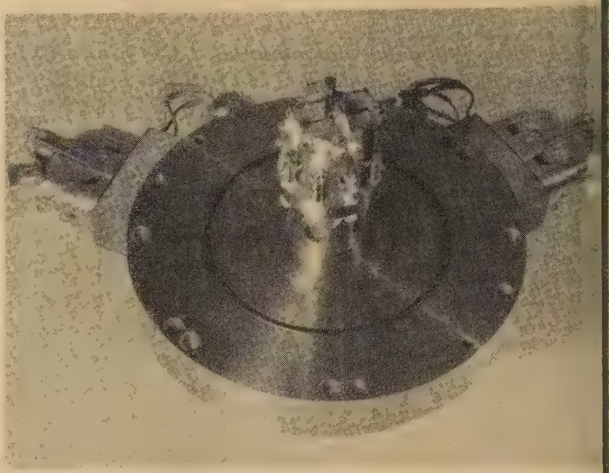


Fig. 10. Photograph of the complete assembly corrector and deflector plates

FUTURE DEVELOPMENTS

Improved electron guns. Although the designs so described are adequate for present purposes, it woul advantageous in many applications to use smaller pr and lower accelerating voltages to improve the resolu This can be done at present only by sacrificing inte Haine and Einstein(12) have investigated the performanc conventional electron guns and have concluded that maximum β-values (current density per unit solid ar observed experimentally are in accordance with the t retical limits calculated by Langmuir.(28) Because β-value decreases linearly with accelerating voltage, represents a serious limitation of intensity. Recent work Hibi(29) and Möllenstedt and Sakaki(30) has shown tha the use of special point cathodes working under "fi assisted" emitting conditions, the measured β-value exceed the Langmuir value by a factor of a hundred. S cathodes, which are suitable for operation in demount vacuum systems, have the additional advantage of presen a source size of only a few microns, instead of the u 50–100 μ of conventional guns, with a consequent si fication of the demagnifying system. At present, p cathodes are not easy to construct but the difficulty app to be technical rather than fundamental.

Correction of spherical aberration. The harmful effec spherical aberration is more easily overcome in a mi analyser than in an electron microscope. In the latter, resolution limit set by spherical aberration and diffrac as $C_s{}^{1/4}$. Consequently, a ten-thousandfold reduction of ld have to be made in order to improve the resolution order of magnitude. The correcting device must also stringent stability requirements if the improved ng power is to be achieved in practice.

he micro-analyser, the problem is to obtain the maxi- ossible current in a probe of given size. This current rsely proportional to $C_s^{2/3}$ [equation (4)]; for example, ld increase of current would be obtained by reducing a factor of 33. Archard(31) has already proposed a able electrostatic system for an electron probe that is om primary spherical aberration. A later version(32) system using magnetic elements has similar electron- properties but avoids the constructional and opera- difficulties associated with electrostatic lenses. Develop- along these lines should simplify the problem of ing sufficient intensity for the micro-analysis of light ts such as oxygen and carbon.

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pinner-magnetometer for thermal demagnetization experiments on rocks

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A spinner-magnetometer has been built to obtain continuous records of the magnitudes and directions of the remanent magnetic moments of rock specimens while they are heated to temperatures up to 800° C. The specimens are rotated at 78 c/s in a non-inductive electric furnace through which a flow of inert gas is maintained, and the voltages which are produced in a large detecting coil outside the furnace are amplified and measured electronically.

wide study of palaeomagnetism has necessitated the uction of magnetometers in an increasing number of tories in various countries. There are two distinct of magnetometer: astatic, which generally conform ably closely to the design of Blackett(1); and spinner or rock-generator, for which designs have been described by Johnson and McNish,(2) Johnson, Murphy and Torreson,(3) and Bruckshaw and Robertson.(4) For the purpose of the modification to measure heated rocks, the spinner type has two advantages: (i) it is less sensitive to temperature changes;

and (ii) no handling of the specimens is needed to obtain independent measurements of the magnitudes and directions of their magnetizations at high temperatures.

DESIGN DETAILS

Shaft and bearings. The essential mechanical part of the instrument is a vertical brass shaft, which is held in position by two bearings, *U* and *L* as indicated in Fig. 1. Both bearings are self-alining, which obviates the need for fine adjustments, and the lower one has a thrust face to support the weight of the shaft. The bearing surfaces are phosphor bronze and stainless steel, collars of phosphor bronze having been hard-soldered on to the shaft at the two bearing surfaces. The slight magnetism of the stainless steel is not important because the only parts made of this material are stationary.

A light lubricating oil (Vitrea 13, by Shell) is pumped to the central groove of each bearing *via* inlets *I* at a pressure of 50 lb in.$^{-2}$ and removed from the ends *via* outlets *E*, the escape of oil along the shaft being prevented by neoprene-oil seals. The oil is circulated by a small gear pump and an automobile-oil filter is included in the pressure line to the bearings. The oil remains completely clear if the filter is changed every 200 hours of operation.

The shaft is driven by a leather belt of circular cross-section from a 3000 rev/min synchronous motor, the diameter of the pulley *P* being adjusted to give a speed of 4680 rev/min (78 c/s) to the shaft. The whole instrument is mounted on a wooden board which is screwed to a laboratory wall.

Specimen holder. The requirements of the specimen holder and top section of the shaft are that they should retain considerable strength at 800° C and should also be completely non-magnetic. Stainless steel is magnetically unsatisfactory, but it has been found that Inconel and Nimonic (by Mond Nickel Co.) are both suitable materials if the highest sensitivity is not required. The specimen holder (*N* in Fig. 1) which has given twelve months' satisfactory service was machined from Nimonic 80A and mounted on an Inconel tube *R*, $\frac{7}{8}$ in. O.D. by 22 s.w.g. A tube is used to support the specimen holder so that the necessary strength is accompanied by the minimum thermal conduction. Heating of the upper bearing by conduction down the shaft is further prevented by a coupling *J* which includes a $\frac{1}{4}$ in. disk of bakelite.

Specimens *S* are generally cylinders 35 mm in diameter and roughly 35 mm long, and are held in place by grub screws. A small hole ($\frac{1}{8}$ in. diameter) is drilled into the side of each specimen for locating one of the screws, to prevent movement of the specimen with respect to the holder. The specimens cannot be clamped tightly as in the normal use of grub screws because this causes them to split when heated.

Magnetism of the specimen holder sets the limit to the sensitivity of the magnetometer. It gives a signal equivalent to about 3×10^{-4} e.m.u./cm^3 in the specimens, and can be subtracted vectorially from measured moments within an error of about $0{\cdot}5 \times 10^{-4}$ e.m.u. Experiments have only been made on igneous rocks with moments much larger than this error, therefore allowing it to be neglected.

Furnace. The furnace is in two parts. The base *D* is screwed permanently to the wooden mounting board and fitted closely round the Inconel tube which forms the upper end of the shaft. The furnace box *F*, containing the silica tube on which the non-inductive heating element is wound, rests on this base but can be lifted off for handling the specimens. Both the base and the box are made of Sindanyo insulator, free spaces being filled with asbestos wool. The overall width of the furnace is 4 in., this having been kept to a mini in order that the detecting coil *C* should be as clo possible to the specimen holder. The face of the fu

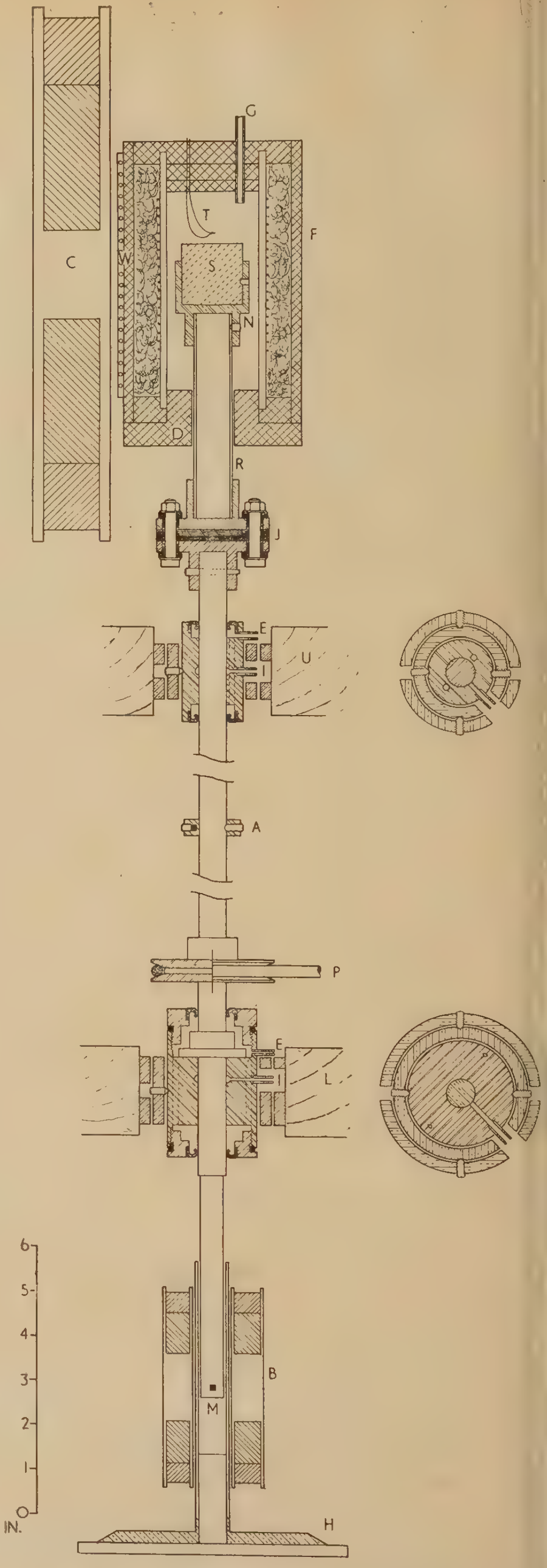

Fig. 1. Mechanical parts of magnetometer

djacent to *C* is cooled by a flow of water through a
of fine copper tubing *W*, which is arranged in a zig-zag
n to avoid making any conducting loops which could
significant eddy currents and interfere with the signal.
low flow of inert gas (nitrogen has generally been used)
the furnace by a silica tube *G* and leaves through the
between the furnace base and the shaft. Rotation of
ecimen holder stirs the gas in the furnace so that it is
he same temperature, measured potentiometrically with
mel-alumel thermocouple *T*.

coil has two sections which are wound in opposite
ions and are shown to scale in Fig. 1. It has 55 000 turns
s.w.g. enamelled copper wire, giving a resistance of
Ω. The total area-turns product for the whole coil
djusted to zero, within half a turn, at the maximum
ter of $11\frac{1}{2}$ in. by connecting it to a sensitive galvano-
and moving it about in the earth's field. The internal
ities of the two sections were equalized by connecting
mer capacitor across the outer one.

ndard signal generator. The voltage induced in the coil
ompared with a standard voltage induced in a pair of
connected coils *B* by an Alnico magnet *M*, 0·3 in.
y 0·12 in. square, glued into a hole at the bottom of
aft. Each of these coils is also wound in two sections
plastic former, using 3600 turns of 29 s.w.g. enamelled
r wire, and the pair is mounted on a turntable with a
H, marked in degrees. This mounting allows the coils
rotated about the axis of the shaft, giving a continuous, known variation in the phase of the standard signal. The coils *B* give a steady voltage of 0·25 V, r.m.s., the amplitude of which is independent of the phase.

The spurious voltage which is induced in the detector coil *C* by the standard magnet is cancelled by a smaller compensating magnet enclosed in the collar *A* which can be clamped in any position on the shaft. The position of the collar which resulted in zero signal in the detector coil when the magnetometer was run with no specimen was found by trial and error.

Electronic circuits. The amplitudes of the test and standard signals are compared by means of the balancing amplifier, shown in Fig. 2, the output being fed to a narrow-band amplifier (of which the circuit is indicated in Fig. 3) and a multirange voltmeter. V_2 and V_3 in Fig. 2 amplify the test signal by between 3×10^3 and 3×10^4, depending upon the setting of the feedback control resistor RV_{14}. The high gain is achieved by using the principle of starved amplifiers.(5) The phase shifts, within the amplifier, of the test and standard signals are adjusted to exact equality by RV_{22} and RV_{30}. S_1 is a decade attenuator switch, having six positions, with which the test signal is attenuated by between 1 and 10^5, within 0·1%. When this has been adjusted, a balance of the amplitudes of the two input signals is obtained with the 10-turn helical potentiometer RV_{26} which has a scale for which an accuracy of 0·1% of the full scale is also claimed by the manufacturer. Phase balance between the test and standard signals is obtained by rotating the standard coils *B*.

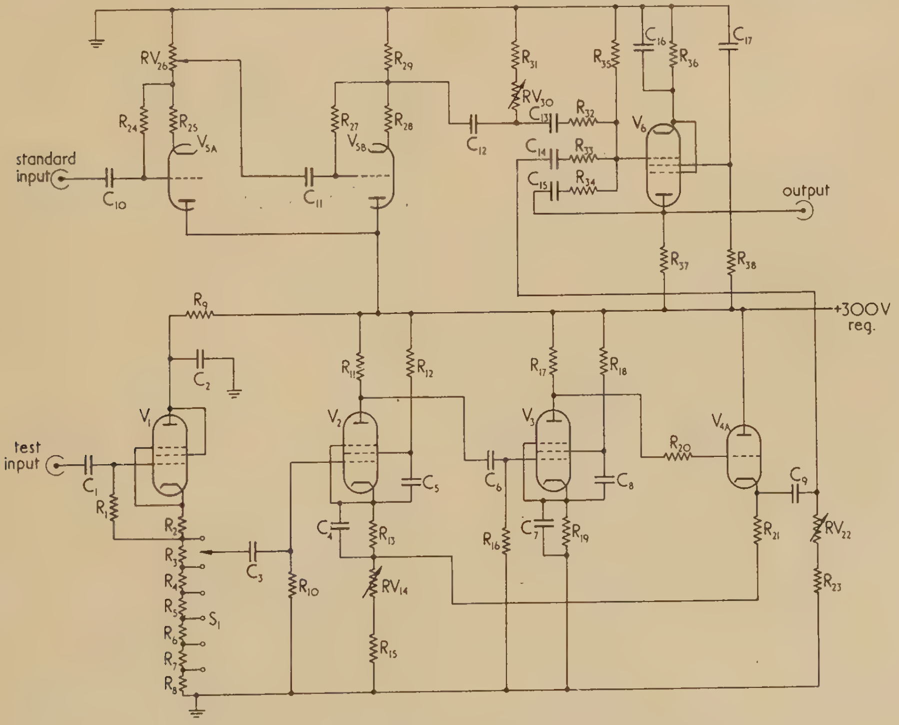

Fig. 2. Circuit of balancing amplifier

= 10 MΩ
= 2·2 kΩ
= 100 kΩ ± 0·1%
= 10 kΩ ± 0·1%
= 1 kΩ ± 0·1%
= 100 Ω ± 0·1%
= 10 Ω ± 0·1%
= 1·11 Ω ± 0·1%
= 47 kΩ
= 10 MΩ
= 2·2 MΩ
= 12 MΩ
= 10 kΩ

RV_{14} = 10 Ω potentiometer

R_{15} = 1 Ω
R_{16} = 10 MΩ
R_{17} = 2·2 MΩ
R_{18} = 12 MΩ
R_{19} = 10 kΩ
R_{20} = 47 kΩ
R_{21} = 47 kΩ

RV_{22} = 2 MΩ potentiometer

R_{23} = 100 kΩ
R_{24} = 2·2 MΩ
R_{25} = 2·2 kΩ

RV_{26} = 100 kΩ, 10-turn helical potentiometer, 0·1% scale

R_{27} = 2·2 kΩ
R_{28} = 1·2 kΩ
R_{29} = 47 kΩ

RV_{30} = 2 MΩ potentiometer

R_{31} = 100 kΩ
R_{32} = 270 kΩ
R_{33} = 270 kΩ } matched values
R_{34} = 270 kΩ
R_{35} = 1 MΩ

R_{36} = 2·2 kΩ
R_{37} = 220 kΩ
R_{38} = 1 MΩ

C_1 = 0·047 μF
C_2 = 16 μF
C_3 = 0·047 μF
C_4 = 25 μF
C_5 = 8 μF
C_6 = 0·047 μF
C_7 = 25 μF
C_8 = 8 μF
C_9 = 0·1 μF
C_{10} = 0·047 μF

C_{11} = 0·047 μF
C_{12} = 0·1 μF
C_{13} = 0·047 μF
C_{14} = 0·047 μF } matched values
C_{15} = 0·047 μF
C_{16} = 25 μF
C_{17} = 8 μF

V_1 = E80F
V_2 = E80F
V_3 = E80F
V_4 = E80CC } (both halves)
V_5 = E80CC
V_6 = E80F

The tuned amplifier (Fig. 3) is included principally to eliminate stray signals with frequencies other than 78 c/s. It operates on a principle described by Valley and Wallman(6) which allows very sharp tuning, so that it has been found convenient to spread the bandpass by varying the components of the twin-T networks to give 3 dB points on the response curve at frequencies which are 2·5 c/s above and below 78 c/s. The strong discrimination against 50 c/s noise is a necessary precaution in the laboratory where this magnetometer is used.

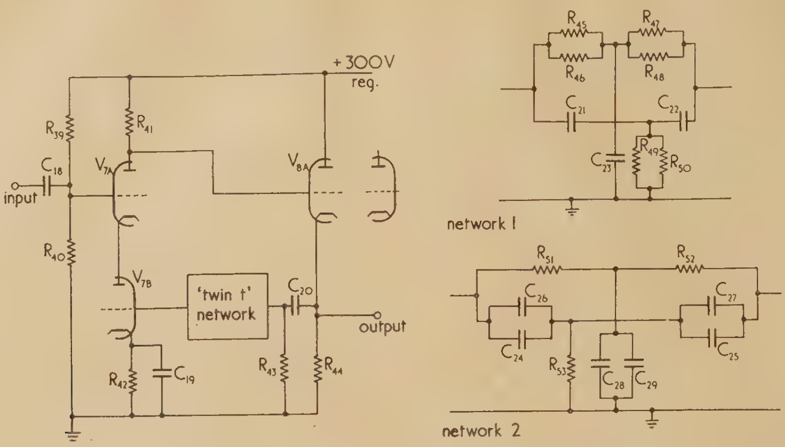

Fig. 3. Circuit for narrow-band amplifier

$R_{39} = 2{\cdot}2\ \text{M}\Omega$
$R_{40} = 820\ \text{k}\Omega$
$R_{41} = 220\ \text{k}\Omega$
$R_{42} = 5{\cdot}6\ \text{k}\Omega$
$R_{43} = 1\ \text{M}\Omega$
$R_{44} = 270\ \text{k}\Omega$

$R_{45} = 6{\cdot}8\ \text{M}\Omega$
$R_{46} = 220\ \text{k}\Omega$
$R_{47} = 6{\cdot}8\ \text{M}\Omega$
$R_{48} = 220\ \text{k}\Omega$
$R_{49} = 110\ \text{k}\Omega$
$R_{50} = 3{\cdot}3\ \text{M}\Omega$

$R_{51} = 180\ \text{k}\Omega$
$R_{52} = 180\ \text{k}\Omega$
$R_{53} = 90\ \text{k}\Omega$

$C_{18} = 0{\cdot}1\ \mu\text{F}$, 200 V wkg.
$C_{19} = 20\ \mu\text{F}$, electrolytic, 12 V wkg.

$C_{20} = 0{\cdot}25\ \mu\text{F}$, 200 V wkg.
$C_{21} = 0{\cdot}01\ \mu\text{F}$, mica
$C_{22} = 0{\cdot}01\ \mu\text{F}$, mica
$C_{23} = 0{\cdot}02\ \mu\text{F}$, mica
$C_{24} = 0{\cdot}01\ \mu\text{F}$, mica
$C_{25} = 0{\cdot}01\ \mu\text{F}$, mica

$C_{26} = 0{\cdot}0012\ \mu\text{F}$, mica
$C_{27} = 0{\cdot}0012\ \mu\text{F}$, mica
$C_{28} = 0{\cdot}02\ \mu\text{F}$, mica
$C_{29} = 0{\cdot}0024\ \mu\text{F}$, mica
V_7 = 12AU7 (both halves
V_8 = 12AU7

PRECAUTIONS AND ADJUSTMENTS

Extraneous signals. The method of eliminating stray signals by winding coils in two sections is quite generally used. Nagata(7) stated that no net voltage was induced in such coils by a uniform change in a uniform field. The cancellation is, in fact, better than this because, if the coil is completely symmetrical, there is no net induction by a change in uniform field gradient. The addition of the trimmer capacitor across the outer section of the detector coil was found to be only a very small refinement. It would have been much more significant if the inner and outer sections of the coil had been wound in the same direction so that, when connected in series-opposition, an appreciable voltage appeared across the surface between the two sections. The only purpose of the trimmer capacitor is to perfect the cancellation of stray signals by adjusting the phases of these signals to exact opposition in the two halves of the coil.

Eddy currents. The importance of eddy currents was realized when a 0·03 in. sheet of copper, intended to cool the face of the detector coil, was placed temporarily between the specimen and the coil, attenuating the signal by a factor 6 and changing its phase by 80°. The only stationary metal parts in the vicinity of the coil are the screws holding it to the wall bracket and the cooling coil of fine copper tubing, which is shown to have no effect by the fact that the signal is unchanged when it is removed.

Eddy currents can also be important in the mounting of the standard-signal coils. Attenuation of this signal is not serious but it has been found that any metal parts in the mounting which do not have complete cylindrical symmetry impart to the stray field of *M* an asymmetry which rotates with the coils. This destroys the compensation obtained collar *A*, which can then only be in correct adjustmen one position of the standard coils.

All metal parts are earthed, including the specimen h which is connected to the shaft by a layer of colloidal gra across coupling *J*.

Adjustment of trimmer capacitor. The phase shifts i two arms of the balancing amplifier were first set to equality by adjusting the phase controls R_{22} and R_{30} wi two amplifier inputs connected to a potential divider car a 78 c/s current from the reference-voltage generator. voltage output indicated correct adjustment of these co within 0·1° and also of the amplitude controls. The signal" and "standard signal" input terminals of the am were then connected to the two sections of the detecto in which voltages were induced by a small "Alcomax" m rotating in the specimen holder. The signals were bal by means of the amplitude controls and the trimmer cap which was then in correct adjustment for phase balan the two sections of the detector coil.

Temperature of specimens. During a run, spe temperature rises at about 1·5° C per minute, so measurements are made continuously instead of waitin thermal equilibrium for each reading. At this rate of hea the temperature at the centre of the specimen lags b that of the gas by about 5° C. To check the magnitu this lag, a thermocouple was temporarily fixed into specimen holder at the bottom of the specimens, and to it were taken out *via* slip-rings lower down the The thermal demagnetization curve of rocks which have examined indicate that no loss of information results this temperature spread. It allows a run to 600° C completed comfortably in a normal day's work. If gr temperature resolution is required, the heating rate ca reduced.

Sensitivity. Although some improvement in sensi would result from the use of a specimen holder with magnetism, this instrument cannot, in principle, appr the sensitivity of a magnetometer which does not use h specimens. This is a result of the very strong dependen sensitivity on the distance between the detector coil an specimen, which cannot be made very small because o intervening furnace material.

alibration. The magnetometer is calibrated by means of ndard specimen consisting of a small "Alcomax" magnet d into a Perspex "specimen", the moment of the standard ng been determined from its period of oscillation in the 's field. The amplifier gain may be checked indepen- ly, if necessary during a run, by means of the potential ler used for phase adjustments. Generally, however, ive and not absolute values of magnetic moment are ired, so that exact calibration is not important.

MEASUREMENTS

esults have been obtained for about 30 specimens h fall into two categories between which it is important ifferentiate in palaeomagnetic work. These are rocks in h the direction of the natural moment changes very or not at all with increasing temperature and those in h it changes by a large angle. The magnetometer is itive to changes of 0·25° and only two of the specimens found to have moments constant in direction within this . At the other extreme, changes up to 90° have been rved.

e particular advantage of thermal demagnetization over alternating-field method is that the magnetothermal ory of a specimen can be inferred from the former. This particularly valuable with two meteorite samples, for h demagnetization curves and a probable magnetic ory have been given in a preliminary report.(8)

o spontaneous reversals of magnetic moments have been rved in the specimens examined so far, although some of them had natural moments opposite to the sense of the present geomagnetic field.

ACKNOWLEDGEMENTS

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Weight-in-air basis of adjustment of precision weights

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An explanation is given of the advantages and the limitations of the arrangement whereby analytical and similar weights of accuracy approaching one part per million (for example, 0·1 mg on 100 g) are adjusted and tested on the basis of weighings in air without applying buoyancy corrections. The paper has been occasioned by a decision taken recently by a number of national standards laboratories, including the National Physical Laboratory, to base their weight-in-air tests, as from 1 July, 1959, exclusively on the densities 8·0 g/ml. for the weights and 0·0012 g/ml. for the air.

INTRODUCTION

he adjustment and use of weights to ordinary accuracy buoyant effect of the ambient air can often be ignored. the other hand, in the very accurate calibration of ision weights, for example the derivation of stainless reference kilogrammes from basic platinum-iridium dards of mass, the difficulty of assessing buoyancy closely ugh (due to imperfect knowledge of the air density) may stitute the ultimate limitation on accuracy. Between these extremes there lies a level of accuracy, one part per ion (1 p.p.m.)—corresponding, for example, to 0·1 mg 100 g—for which buoyancy must be taken into account, nevertheless may be disposed of very simply on a con- ional basis. In this country, for instance, ordinary ision weights are adjusted and verified on a routine basis omparison (in principle*) in air of density 0·0012 g/ml. with mass standards of a conventional density representing the densities of the major weights of similar sets.† The same conventional density is associated with all the weights of a given set, irrespective of their individual densities, and no buoyancy allowances are made. This basis of adjustment and calibration, known as the "weight-in-air basis," has notable advantages. Not only is the complication of buoyancy allowances eliminated from manufacture and testing,

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In practice, N.P.L. calibrations to 1 p.p.m. are effected against s standards of approximately, but not exactly, the conventional density adopted. Average allowance is made, once and for all as part of the value of the standard, for the departure of the actual density from the conventional density, this allowance being based on the reference air density 0·0012 g/ml. The calibrations are carried out in air at about 20° C and at the atmospheric pressure current at the Laboratory, which is close to mean sea level, so the density of the local air differs little from 0·0012 g/ml. The consequent buoyancy errors affecting the calibration are thus quite secondary.

† Gould, F. A. *Proc. Roy. Soc. A*, **186**, p. 177 (1946); *National Physical Laboratory, Notes on Applied Science No. 7, Balances, weights and precise laboratory weighing*, p. 33 (London: H.M. Stationery Office, 1956).

but in service buoyancy allowances are much facilitated; whatever the total value (P) of the weights used, including fractional weights of whatever metal, the overall buoyancy correction is merely $P\sigma/D$ (σ is the density of the ambient air and D is the conventional weights density concerned), not $\Sigma P_n\sigma/D_n$. On this basis, for the larger weights of the set and for the smaller weights of similar material, the error of the corrected value would only very unusually amount to one part per million and for small weights of platinum (21·5 g/ml.) or aluminium (2·7 g/ml.) the error does not exceed a few microgrammes.

The N.P.L. adopted a weight-in-air basis for its routine tests to 1 p.p.m. many years ago, when the major weights were almost exclusively made of plain or plated brass (8·5 g/ml.). Some allowance was made for the presence of closed adjustment-cavities and the value adopted for D was 8·4 g/ml. Stainless steel weights, however, when they became available, could not be admitted to test on the 8·4 g/ml. basis owing to the greater potentiality for buoyancy error which arose from their relatively small density 7·8 g/ml. (see below). A second conventional basis was therefore introduced. For this basis not 7·8 g/ml. but 8·0 g/ml. was adopted, in the hope that wide unification for all weights might eventually be achieved on this round figure.

RECENT DEVELOPMENTS

Events have now moved a stage further and the N.P.L. is pleased to announce, after recent discussions between the Directors of the national standards laboratories in Australia, Canada and the United States, that the four laboratories (including the N.P.L.) will use the 8·0 g/ml. basis exclusively in their weight-in-air tests as from 1 July, 1959. The collaboration of the National Bureau of Standards, Washington, which has hitherto used only the 8·4 g/ml. basis, is particularly noteworthy, as is also the ready co-operation of the weights manufacturers in this country.

BASIC CONSIDERATIONS

As the weight-in-air convention is not always fully understood the present occasion is taken to set forth its basis, and various associated implications, in some detail.

Because the materials (plated brass, stainless steel, etc.) commonly used for weights have roughly the same density, weights of the same denomination have about the same volume. Hence the buoyancy differences between them are small and the extent to which these differences vary from time to time are very small. For this reason, it is not only convenient, but usually adequate to adjust and verify weights by direct comparison with mass-standards of average density without making buoyancy allowances, the average buoyancy differences being regarded as part of the effective values of the weights. The value associated with the weight on this basis is known as the "weight-in-air value". (The term "weight" here, as elsewhere in this paper, refers to a weight-piece, not to the result of a weighing.) It is not, of course, the true mass, but as precision weighings are not made in rarefied air it is not necessary to know the true mass; it is the calculated value of weights-less-buoyancy which is normally relevant. Under normal conditions of weighing this value will be but little in error, provided it is based on the density of the mass standard against which the weights are adjusted or verified. For reasons which will become more apparent below, it is convenient in practice if all weight referred to a single conventional density.

As the density of air under normal conditions (a 0·0012 g/ml.) is approximately one part in 7000 of th ordinary weights, such weights experience air buoyanc the extent of about one part in 7000 of their value. buoyancy acting on two weights, one a reference weig the conventional density 8·0 g/ml. and the other an ordi weight differing from it in density by about 7% (7· 8·6 g/ml.), will correspondingly differ by about one par 100 000 of the weights concerned. For air densities var in the range ±10% from nominal (corresponding temperature variation of about ±15° C *plus* a pre variation of about ±35 mm of mercury) the variation d buoyancy is about ±1 p.p.m. This provides a satisfac basis for adjusting and certifying weights which are req to be known to about 1 p.p.m.

Of course the materials used for *small* weights b means conform to the density limitations stated above. example, platinum has a density of 21·5 g/ml. and alumi 2·7 g/ml. One gramme of platinum displaces 60 μg o and one gramme of aluminium 450 μg, whereas a weig conventional density 8·0 g/ml. displaces 150 μg. buoyancy differences in relation to normal materials accordingly 90 and 300 p.p.m. respectively, and the varia in these buoyancy differences due to an air density var of ±10% are therefore ±9 and ±30 p.p.m. Conseque weights of these materials up to a total of 1 g for plati and 0·1 g for aluminium can safely be treated on the 8·0 g weight-in-air basis, without incurring errors exceedi usual N.P.L. accuracy of certification ±10 μg for fracti weights.

At this stage it is perhaps desirable to explain rather precisely than before why stainless steel weights were ju inadmissible to the N.P.L. tests on the 8·4 g/ml. b Importance was then attached to the strict maintenanc buoyancy-corrected weight-values of an *overall* accurac 1 p.p.m., this allowance including not only the resi buoyancy-error but also provision for both weighing e in standardization and the calibration error of the refer standards. The differential buoyancy between stainless (7·8 g/ml.) and a material of density 8·4 g/ml. is 11 p. If a stainless steel weight contains a closed cavity (a ca beneath the knob is frequently used for adjustment purpo the differential buoyancy is even greater. Hence, in ser departures of air density from the basic value could a introduce errors of 1 p.p.m. or more, and in these circ stances the 8·4 g/ml. basis was regarded as inappropriate the new material.

ADVANTAGES OF USING 8·0G/ML. EXCLUSIVE

The exclusive adoption of 8·0 g/ml. as the weight-in basis for all sets will limit the residual buoyancy error service to ±1 p.p.m. or less. It will also ensure that, in the most exceptional circumstances, the major wei adjusted on a weight-in-air basis will balance one ano within 2 p.p.m. and the fractional weights up to 1 g wil so within 10 μg; indeed, in air of density 0·0012 g/ml. will balance one another precisely, irrespective of mate More important, however, instances of disagreement betw sets, due to adjustment on different bases, will be consider reduced and eventually eliminated as between sets mad this country. At present, owing to the coexistence of diffe bases, some sets of weights disagree considerably w pared in air. This tends to happen particularly when a nce incorporating built-in dial-loaded weights is checked nst an independent set. Naturally such disagreements resolved when buoyancy allowances are made on the ropriate bases. But these disagreements are nevertheless nvenient and they may be perplexing if it is not realized different bases are concerned.

EVALUATION OF DIFFERENCES

he following basic equations are set down for the benefit hose who may find that the differences are thus more lily understood and evaluated. Consider the adjustment weight of mass M grammes and density Δ g/ml.

) *Adjustment on the* 8·4 : 0·0012 *g/ml. basis*; i.e. the ie P_a associated with the weight is the mass of a hypo- ical weight of density 8·4 g/ml., which in air of density 012 g/ml. balances the weight.

he equilibrium is expressed as follows:

$$M - (M/\Delta) \times 0{\cdot}0012 = P_a - (P_a/8{\cdot}4) \times 0{\cdot}0012$$

nce

$$P_a = M\left(1 - \frac{0{\cdot}0012}{\Delta}\right) \Big/ \left(1 - \frac{0{\cdot}0012}{8{\cdot}4}\right) \tag{1}$$

) *Adjustment on the* 8·0 : 0·0012 *g/ml. basis*; i.e. the ie P_b associated with the weight is the mass of a hypo- ical weight of density 8·0 g/ml., which in air of density 012 g/ml. balances the weight.

 these circumstances

$$P_b = M\left(1 - \frac{0{\cdot}0012}{\Delta}\right) \Big/ \left(1 - \frac{0{\cdot}0012}{8{\cdot}0}\right) \tag{2}$$

) *The relation between the two bases of adjustment.* This iven by

$$P_a/P_b = \left(1 - \frac{0{\cdot}0012}{8{\cdot}0}\right) \Big/ \left(1 - \frac{0{\cdot}0012}{8{\cdot}4}\right)$$

$$= 0{\cdot}999\,992\,9$$

refore in air of density 0·0012 g/ml., a 100 g weight (for nple) from a set based on 8·4 g/ml. will balance)/0·999 992 9) g, i.e. 100·000 71 g, from a set based on g/ml. It will be noted that the ratio is proportional to omination but independent of Δ, i.e. of the materials cerned. To derive values relative to the 8·0 g/ml. basis from those relating to 8·4 g/ml. a uniform addition of 7·1 p.p.m. must be made.

The relationships (1) and (2) also indicate the differences between weights adjusted on the weight-in-air basis and on the basis of true mass. These differences depend on the actual density of the weights and are evaluated in the table.

Differences, for weights of various densities, between their weight-in-air values and their masses

Density of weight	*Weight-in-air value on the basis 8·0 or 8·4 g/ml. as indicated (to be corrected for buoyancy on the respective bases), less mass (to be corrected for buoyancy on the basis of the actual density as shown in the first colnmn)*	
(*g/ml.*)	8·4 *g/ml. basis (mg/g)*	8·0 *gm/l. basis (mg/g)*
21·5	+0·087	+0·094
9·0	+0·010	+0·017
8·5	+0·002	+0·009
8·4	0	+0·007
8·0	−0·007	0
7·5	−0·017	−0·010
7·0	−0·029	−0·021
2·7	−0·030	−0·029

CONCLUSION

In the above notes the simplicity of the weight-in-air basis in weighing practice has been indicated, and the advantages of a common density convention for all sets, irrespective of material, have been demonstrated. The two bases, 8·0 and 8·4 g/ml. will inevitably coexist for some time to come, but after 1 July, 1959, all new weights for science and technology will be adjusted and tested on the one basis of 8·0 : 0·0012 g/ml., and it is hoped that the time is not too far distant when weights for all purposes will be adjusted to this basis. At present, under the requirements of the Board of Trade, a third weight-in-air basis (8·136 : 0·001 217 g/ml.) intermediate between the two discussed above is in use for weights subject to the Weights and Measures Acts, but it is hoped that they too may be brought into the 8·0 : 0·0012 g/ml. convention as one of the consequences of the new Weights and Measures Bill which will be considered when Parliamentary time permits.

ACKNOWLEDGEMENTS

This paper has been prepared and is published by permission of the Director of the National Physical Laboratory.

Revised edition of *Notes for authors*

The Institute of Physics has recently published a 36-page revised edition of its booklet intended to assist less-experienced authors and to serve as a reference booklet for all those who wish to contribute to the Institute's publications. Under its new title *Notes for authors*, it gives hints on the preparation of scripts and diagrams, on the layout of mathematics, the correction of proofs and so on. In addition to a bibliography of reference books and works on technical writing, the pamphlet also contains lists of the spellings, symbols and abbreviations used by the Institute. These conform with British Standard 1991: Part I: 1954: *Letter symbols, signs and abbreviations, Part I, General* which authors of mathematical papers are also advised to consult.

Authors preparing contributions for submission to this *Journal* are invited to make use of the guidance available in the booklet, copies of which may be obtained from The Institute of Physics, price 3*s*. 6*d*. (including postage).

Time-controlled unit-function, constant-voltage generator

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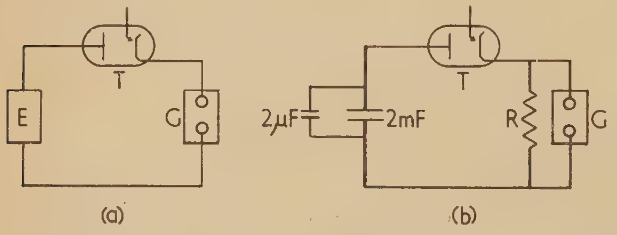
[*Paper received* 1 *April*, 1959]

A time-controlled, unit-function, constant-voltage generator has been developed having a variable output amplitude from 40 to 1000 V with a rise time of 1 μs and constant for 150 μs. The output voltage is independent of current from 0 to 12 A and can be applied with an accuracy of ±1 μs. The generator consists of a source of high-capacity capacitors connected in parallel with non-inductive capacitors which supply the initial energy at a high rate. A mercury thyratron (type BT61A) with a special triggering circuit gives the necessary time control. By keeping the thyratron at a constant temperature, its appropriate volt-ampere characteristic shows that the voltage amplitude is maintained constant independent of variation in current output. A high rate of rise of the unit function is achieved by connecting a high-voltage auxiliary circuit between anode and cathode. Detailed circuit diagrams of the generator, etc., are given. The effects of temperature, accentuation of field due to additional space charge and oscillations on the voltage waveform are also discussed.

The electrical conductivity of a decaying arc-plasma can be determined at any instant during the decay by applying a unit function probing voltage to the plasma. If the probing voltage amplitude can be maintained constant and independent of the current output of the generator, then measurements may be made of the reignition condition of the plasma. In order to carry out such investigations the authors have developed a generator that meets the stringent requirements set by the experiment. These requirements demand the following properties of the unit function probing voltage.

(*a*) A rise time of ⩽1 μs.
(*b*) Constant amplitude to ±2·0% for 150 μs.
(*c*) Amplitude independent of current output and its variation up to 12 A.
(*d*) Output amplitude to be variable from 40 to 1000 V.
(*e*) The output voltage to be applied at any given delay time with an accuracy of ±1 μs.

Most of the conditions can be met by using a thyratron circuit with a capacitor or battery source. However, real difficulty is met when attempting to satisfy conditions (*c*) and (*d*), since most thyratrons have a variable voltage drop with current and are difficult to fire at anode voltages as low as 40 V. Again, at such low voltages the rate of rise of current will be relatively slow and make condition (*a*) difficult to attain. These difficulties have been overcome by using a large mercury thyratron (type BT61A),(1) with special auxiliary anode and triggering circuits, and by developing the output current across a resistor. The basic generator circuit is depicted in Fig. 1(*a*), and comprises a voltage source *E*, a thyratron *T* and a test gap *G*, all connected in series. The additions to this circuit, which are required in order to satisfy conditions (*a*) to (*e*), are described in the following sections.



(a) (b)

Fig. 1(*a*) and (*b*). Basic circuit of the constant voltage generator

VOLTAGE REGULATION OF THE GENERATOR

The experiments demanded that the voltage across the t gap *G* should remain constant for approximately 150 μs a independent of variation in current through the plasma in up to a value of approximately 12 A. Thus series resista cannot be used for voltage control and the impedanc the circuit must be reduced to a minimum. With no resist in the circuit, the voltage regulation across *G* is then enti controlled by the internal impedance of the source *E*, a the variation in the voltage drop with conduction in valve *T*.

To reduce the internal drop in the voltage source, batteries or high capacity capacitors may be used. Si voltage control of a capacitor bank is simpler and m continuously variable than for a battery, the authors ch number of 2000 μF capacitors as their voltage source. capacitors had, however, relatively large inductance wh reduced the initial rate of current output from the capacit thus reducing the rate of rise of the unit function volt output. This effect was overcome by connecting a relati non-inductive capacitor of 2 μF in parallel with the 2000 units as shown by Fig. 1(*b*). The initial current output fr the source is thus supplied by the non-inductive capacito

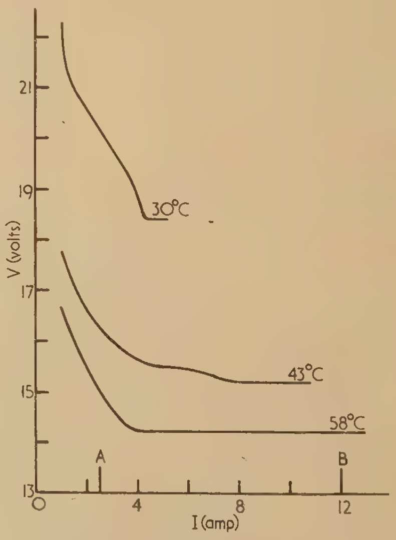


Fig. 2. Volt-ampere characteristics of the mercury thyratron type BT61A

high rate. The results showed an appreciable reduction)%) in the rise time of the unit function.

The effect of the valve upon the generator regulation was termined by measuring the volt-ampere characteristic of type BT61A valve at different temperatures, the valve ing placed in an oil bath. The characteristics obtained are ven by Fig. 2. Since the conductivity of the plasma in the t gap is very low after long periods of decay, the initial rrent through the valve on application of the unit function ltage to the plasma will also be very small. This means at the valve will commence operation in the current range 4 (Fig. 2) in which the voltage drop varies greatly with rrent. This difficulty can be overcome by connecting, in rallel with the test gap, a resistor having a value such that initial valve current is brought within the current range 3 in which the voltage drop remains sensibly constant. In actice, the authors use the 58° C characteristic and allow initial valve current of 2·5 A. Thus the conduction rough the test gap can increase from 0 to 12 A with a riation of the test gap voltage of only ±0·5 V. Even at lowest test voltage of 40 V this represents only ±1·25%.

THE GENERATOR OUTPUT WAVEFORM

With this method of plasma conductivity measurement the curacy is increased with increase in rate of rise of applied ltage. Simple triggering of the circuit of Fig. 1(*b*) with test gap removed showed that at 50 V the current took μs to rise to 80% of its final value, and that the voltage ross *R* was in phase with this current. This slow rise of itput voltage was unsatisfactory and was obviously due to nitation of current increase in the valve accentuated in the se of low anode voltage. The initial rate of rise was iproved by developing a triggering circuit which pulses the xiliary anode with 400 V and causes a current of approximately 30 A to flow in the auxiliary circuit for approximately μs. The circuit used is shown in Fig. 3(*a*). With this cuit it was found that the anode output waveform depended itically upon the value of the resistor *R*. Thus with small lues less than 100 Ω, oscillations were generated in the xiliary circuit which were reflected in the anode output. n the other hand, with $R \geqslant 1500\ \Omega$ the valve failed to nite. A value of 120 Ω was chosen which damped the cillations and did not cause any appreciable reduction in e voltage output rise time. Fig. 4(*a*) shows an oscillogram of the output voltage taken with this auxiliary anode circuit and at an anode voltage of 200 V. It will be observed that there is a 25% voltage rise in 0·8 μs which is succeeded by a much slower rise in voltage for 5 μs. The initial rapid rise of current is associated with a field accentuation produced by a heavy initial net space charge in the auxiliary anode-cathode region. As the auxiliary anode current becomes established this space charge will be reduced, consequently reducing the driving field on the main anode current and hence delaying the current growth. The auxiliary current plasma still supplies the electrons for acceleration and ionization to form the main anode plasma. Without this heavy supply of electrons from the auxiliary plasma the valve will not trigger at anode voltage as low as 40 V.

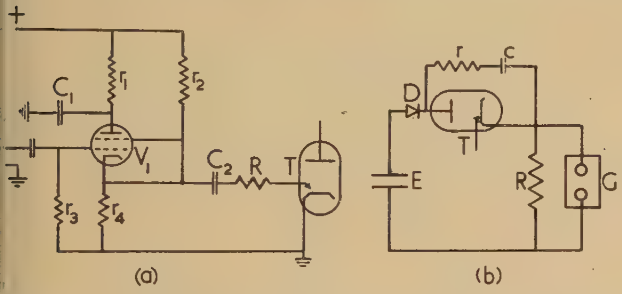


Fig. 3. (*a*) Triggering circuit for the auxiliary anode of the type BT61A thyratron. (*b*) Circuit diagram of the constant voltage generator

$R_1 = 1$ MΩ
$R_2 = 7{\cdot}5$ MΩ
$R_3 = 15$ kΩ
$R_4 = 33$ kΩ

$V_1 =$ 2D21

$C_1 = 0{\cdot}1$ μF
$C_2 = 0{\cdot}1$ μF

$R = 120\ \Omega$

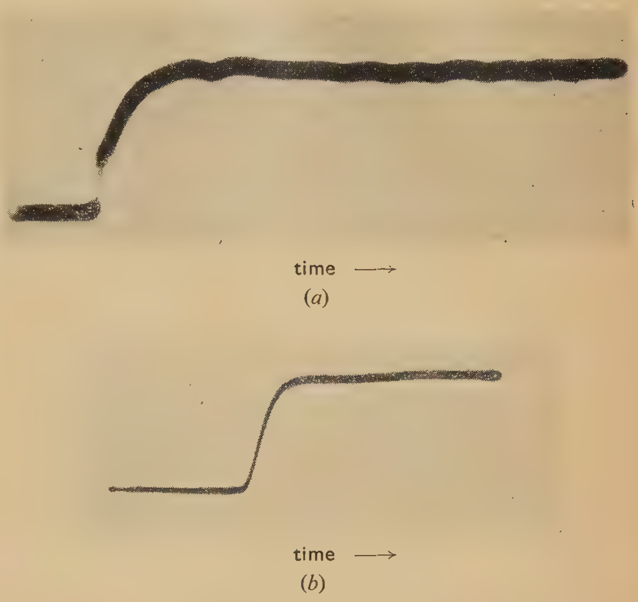


Fig. 4. (*a*) Oscillogram of voltage waveform, taken with the auxiliary anode triggering circuit. Time sweep 50 μs. (*b*) Rise time of the waveform. Time sweep 10 μs

In order to maintain the initial rapid rise of current it is clear that the main anode-cathode field must be increased. Experiment indicated that in order to obtain a full current rise in 1 μs an anode voltage of 300 V was required. This condition has been achieved without affecting the availability of small output voltages by connecting an auxiliary circuit across anode and cathode as shown in Fig. 3(*b*). With this circuit the 0·2 μF capacitor is charged to a high voltage (minimum 250 V) and thus produces a much more rapid breakdown of the valve when the auxiliary anode is fired. The result of this auxiliary firing is exemplified by the oscillogram of Fig. 4(*b*) which shows an output voltage rise time of 1·05 μs. To prevent high voltage feedback into the main circuit a blocking rectifier *D* has been included [Fig. 3(*b*)]. This rectifier must carry the full test gap current up to 12 A for a short time, and a germanium diode, type GEX541/H2PIF is used. Measurements on this diode indicate that the voltage drop across is constant at approximately 0·5 V up to 12 A, and that maximum conduction is attained in 0·4 μs. Thus the diode does not appreciably affect the generator regulation or the rise time. The value of the auxiliary high anode voltage is limited by the inverse voltage of the germanium diode to 250 V.

Some difficulty was encountered in the development of the generator by high-frequency oscillations appearing in the output voltage. The oscillations produced by the circuit on the auxiliary anode have been mentioned. Further oscillations were found when the anode-cathode auxiliary circuit was connected. Such oscillations are presumably connected with variations in the space charge in the valve plasma, which generate potential changes and cut through the valve inductance and the connected rc circuit. It was found that the oscillations could be damped with $r = 10\,\Omega$ [Fig. 3(*b*)].

THEORETICAL DISCUSSION OF THE OUTPUT VOLTAGE WAVEFORM

In a theoretical analysis of the waveform one should bear in mind that during the initial period of ionization the dynamic resistivity of the ionized gap η changes in time, and that also the electric field E varies with respect to time and position and is a function of charge density ρ. An analysis of the waveform is based on the following equations relating the above parameters.

$$\nabla . E = 4\pi\rho \qquad (1)$$

$$(\partial\rho/\partial t) + \nabla . J = 0 \qquad (2)$$

$$\omega(\partial J/\partial t) = E - \eta J \text{ (Ref. 2)} \qquad (3)$$

$$\eta = P/\rho_e j \qquad (4)$$

where J = current density
E = electric field
ρ = charge density
ω = ionization inductance per unit length
η = dynamic specific resistivity of the gap times unit length
P = momentum transferred to the gas per unit volume per unit time.

To a first approximation one can assume that η remains constant and that E does not vary with time. Consider therefore only equations (3) and (4); hence

$$\frac{dJ}{dt} + \frac{\eta}{\omega} J = \frac{E}{\omega} \qquad (5)$$

giving

$$J = J_0 \exp(-\nu t) + \frac{E}{\eta}\{1 - \exp(-\nu t)\} \qquad (6)$$

where $$\nu = \frac{\eta}{\omega}$$

In equation (6) ν represent the frequency of ionization; J_0 is assumed to be the primary current which is produced by the auxiliary anode arc. As was mentioned previously, this current is associated with the net space charge formed in the cathode to auxiliary anode region. The increase in field strength ΔE resulting from additional space charge will affect the ionization in the plasma as is shown below.(3) According to Paschen's law, the number of ionizing collisions per unit length and per unit pressure is:

$$\frac{\alpha}{p} = A \exp\left(-\frac{Bp}{E + \Delta E}\right) = A \exp\left\{-\frac{Bp}{E}\left(\frac{1}{1 + \frac{\Delta E}{E}}\right)\right\} =$$
$$= \frac{\alpha_0}{p}\left\{1 + \frac{Bp}{E^2}\Delta E + \frac{Bp}{E^4}\left(\frac{Bp}{2} - E\right)(\Delta E)^2\right\} \qquad (7)$$

$$\alpha_0 = Ap \exp(-Bp/E) \qquad ($$

The change in the number of ion pairs produced along distance d, resulting from the space charge, is:

$$\int_0^d \alpha dx - \alpha_0 d = \alpha_0 \frac{Bp}{E^2} V + \alpha_0 \frac{Bp}{E^4}\left(\frac{Bp}{2} - E\right)\int_0^d (\Delta E)^2 dx \qquad ($$

V represents the constant potential at a distance d from t cathode. The second term on the right-hand side of equati (9) will be positive if $B/2 > E/p$. Hence the space char will create a more extensive ionization if the pressure is hig and it therefore follows that in order to maintain a hi pressure in a vapour valve a high temperature is require Since the last integral is always positive $(\Delta E)^2$ the effect the space charge on ionization will be the same whether t charge be positive or negative. This last effect on the ra of rise was observed experimentally and seems to be agreement with the theory. It was observed that a reducti of the current which was fed into the auxiliary anode result in a slower rate of rise of the main anode current. In gene the experimental oscillograms of the voltage wavefo [Fig. 4(*a*)] have the same shape as would be expected fr equation (6), and thus show that the simplified assumptio which were made are justified to a first approximation.

CONCLUSIONS

With the circuits described, the requirements of t generator laid down at the beginning of the paper have be satisfied. Fig. 5 gives a typical oscillogram showing t output voltage when transient currents up to 12·5 A a taken. It will be observed that the rise time is 1·05 and that, despite the large varying current output, t amplitude of the unit function remains constant within ±2

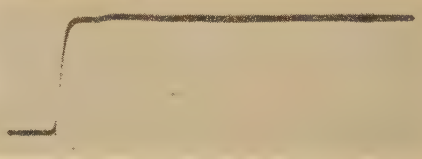


Fig. 5. Oscillogram of output voltage waveform. Time sweep 50 μs

ACKNOWLEDGEMENT

The authors wish to record their appreciation of the inter which Prof. J. M. Meek has shown in the progress of t work and the facilities which he made available to them.

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Measurement of systematic track distortion in a propane bubble chamber

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[*Paper received* 6 *March*, 1959]

A propane bubble chamber, 6 × 2 × 2 in., has been operated with both single-piston and multiple-bellows expansion systems, the systematic distortions caused by turbulent motions being measured and compared in the two cases.

ble chambers have been widely used during the past few rs, but little quantitative information has been published cerning the track distortions occurring with such instrunts. Some of the possible causes of track distortion, cussed by Bassi and others,(1) are: (*a*) non-uniform fluid tion caused by the expansion; (*b*) convective fluid motions to temperature gradients; and (*c*) multiple Coulomb ttering. Measurements made on the photographs will be cted also by distortions due to the optical system.

he effects of multiple scattering are random, but the other cts should be systematic, provided that the movements of expansion mechanism are rigidly controlled. In liquid pane the multiple scattering is large, and any systematic ortion must be evaluated statistically. A large bubble mber employing liquid phase expansion would require a ltiple expansion system, kinematic considerations preventthe use of a single piston or bellows.

hus, as a design study, a small propane chamber has been ed with both single-piston and multiple-bellows expansion systems, the systematic track distortions in the two cases being measured and compared by photographing the tracks of 380 MeV protons.

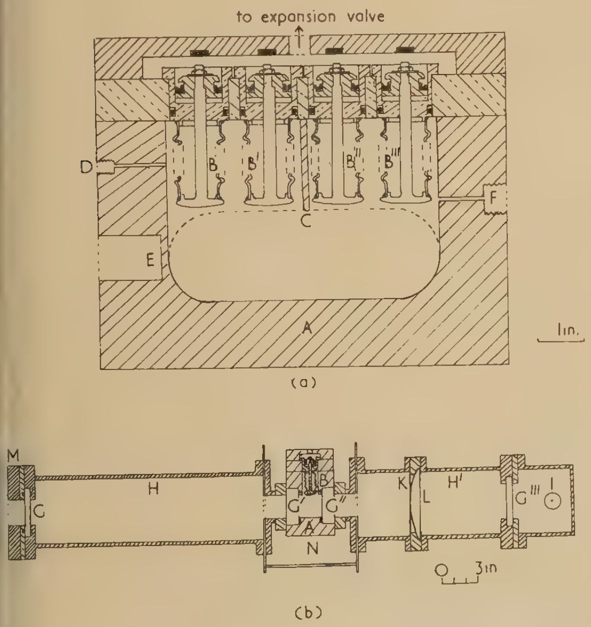

Fig. 1. Chamber with multiple bellows expansion system

(*a*) Longitudinal section.
(*b*) Section showing complete assembly.

A, Duralumin body; *B*, *B*′, *B*″, *B*‴, stainless steel bellows; C, central strengthening strut; *D*, inlet for filling; *E*, beam entry window; *F*, pressure transducer; *G*, *G*′, *G*″, *G*‴, armourplate glass windows; *H*, *H*′, tubular aluminium snouts; , flash tube; *K*, diffusing screen; *L*, condensing lens; *M*, camera mount; *N*, water bath.

CONSTRUCTION OF THE CHAMBER

The chamber, machined from a Duralumin block, had internal dimensions of 6 × 2 × 2 in., with vertical armourplate glass windows, details of the construction with a multiple-bellows expansion system being shown in Fig. 1.

Each of the stainless steel bellows, 1 in. in diameter, had a piston fitted inside it, with stops to ensure that each moved by the same amount during an expansion. A manifold led from each piston to a single $\frac{1}{2}$ in. Barksdale Crescent expansion valve mounted immediately above the bellows assembly.

In order to test the apparatus with the 156 in. synchrocyclotron, and to determine the best method of treating the results, a simple single-piston expansion system (Fig. 2) was initially fitted. The piston was 2 in. in diameter and moved inside a cylinder connected to the chamber through a $1\frac{5}{16}$ in. diameter hole. The control equipment, previously described by Alston and others,(2) was that designed for an earlier bubble chamber.

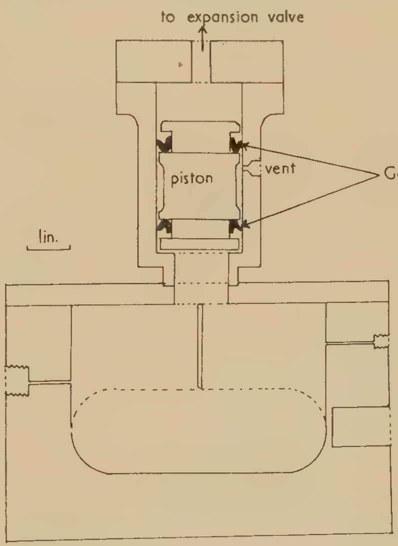

Fig. 2. Single-piston expansion assembly

Bright background illumination was used, a single photograph of the central 4 in. of the chamber being taken, at a magnification of one-eighth, on Ilford Microneg 35 mm film.

When developed in Johnson 468 developer this gave pictures of good contrast and very high resolution.

OPERATING CONDITIONS

Good tracks were obtained with the single-piston system at 61° C, a volume expansion ratio of about 2% and a bubble growth time of 1·5 ms. The chamber pressure fell to its minimum value of 200 lb/in.^{2} gauge in 1·5 ms.

The temperature was raised to 63° C to obtain good tracks with the multiple-bellows system and the bubble growth time was increased to 1·7 ms, the pressure drop now taking 2 ms.

METHOD OF MEASUREMENT

Measurements were made on the film using a Cooke type 4000 binocular microscope with a ×10 objective and a ×10 eyepiece. The diameters of bubble images on the film were approximately 20 μ, measurements being reproducible to 1–2 μ.

The chamber was divided into several horizontal zones for the purposes of measurement. Protons of 380 MV energy suffer appreciable multiple scattering in liquid propane, giving rise to a mean radius of curvature(3) of about 20 m.

In order to measure the systematic distortion in the presence of such large multiple scattering, it was found necessary to measure the deviations from linearity of at least thirty tracks per zone. Measurements at thirteen equally spaced points at fixed values of x were made on each track, only tracks showing no visible single scattering being used. The sets of y co-ordinates for each track were processed by a National Accounting Machine, Class 31, which was programmed to set up the least squares straight line and print out the deviations of each point from this line.

All equivalent points on all tracks in each zone were then summed, giving the mean deviations plotted in Figs. 3 and 4.

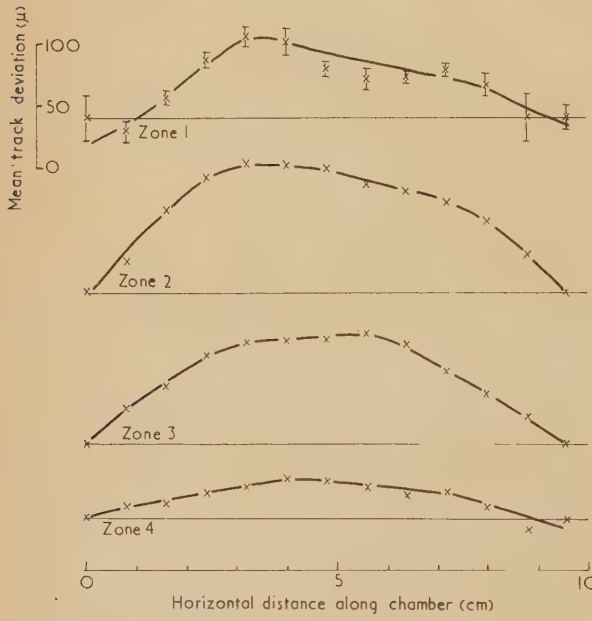

Fig. 3. Deviations with single-piston expansion

The results thus obtained show the total effect of turbulent fluid motion, optical distortion and curvature of the microscope stage. The latter effect was, however, soon shown to be negligible compared with the accuracy of the rest of th experiment.

Optical distortions were measured by determining th apparent curvature of spring-loaded Nylon threads stretche horizontally across the chamber. The top was removed fro the chamber and the threads were arranged on a fram projecting from above into the illuminated region. It w not possible in these circumstances to fill the chamber wit propane (refractive index 1·38) but, since the optical dis tortions were expected to be small, sufficient accuracy w obtained with a filling of water (refractive index 1·33). was found that the image of a straight line 12 mm in lengt had a sagitta of less than 1 μ. The optical distortion was thu negligible in comparison with that due to non-uniform flui motion.

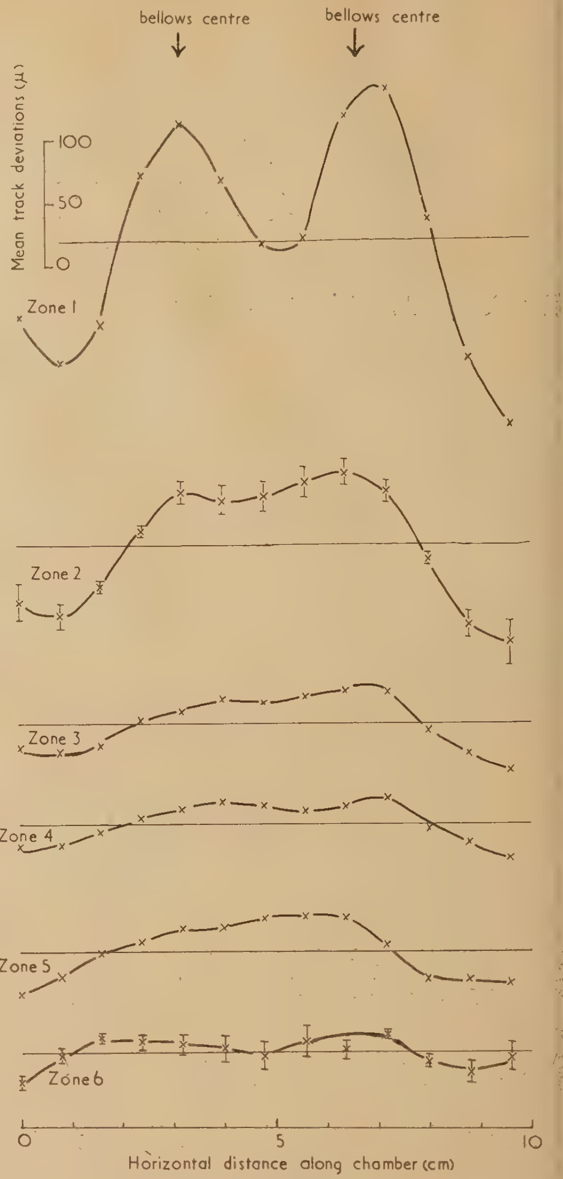

Fig. 4. Deviations with multiple-bellows expansion

DISCUSSION OF RESULTS

Since only single pictures were taken it was not possib to determine the angle made by a track with the plane of the chamber windows. All the tracks measured, ever, traversed the full illuminated length, and were equently confined to the central region of the chamber.

results obtained with the single-piston system are given ig. 3. The chamber image on the film, 6 mm deep, was led into four zones of equal depth and measured as ribed previously.

ne general form of the distortion is as expected, showing onounced mass motion of the fluid beneath the piston. ing into account that each point in the analysis has a dard error of about 1 μ, conditions are nearly uniform he top three-quarters of the chamber. The central ons of the distortion curves tend to be flattened because he presence of the central strut between the bellows' tures.

eviations of the mean track were treated by the method ulwick;(4) the radii of curvature in space and the corresponding proton momenta for a 10 kG magnetic field are vn in the table, in which optical distortions have been n into account.

	Radius of curvature (m)	*Corresponding proton momenta (eV/c)*
e 1	$18{\cdot}6\left({}^{+4{\cdot}4}_{-3{\cdot}0}\right)$	$5{\cdot}6 \times 10^9$
e 2	$10{\cdot}6\left({}^{+1{\cdot}3}_{-1{\cdot}1}\right)$	$3{\cdot}2 \times 10^9$
e 3	$13{\cdot}2\left({}^{+2{\cdot}2}_{-1{\cdot}6}\right)$	$4{\cdot}0 \times 10^9$
e 4	$79{\cdot}2\left({}^{-500}_{-\ 43}\right)$	$23{\cdot}8 \times 10^9$

hese proton momenta may be compared with values of ı 1 to 2 × 10^{10} eV/c quoted by Wilson(5) for tracks of lar length in a good expansion chamber.

should be remembered, however, that the bubble chamber in this experiment was not designed primarily for use a single-piston expansion system.

he distortion pattern obtained with the multiple-bellows insion system is shown in Fig. 4, the chamber being led into six zones of equal depth. The induced curvatures generally greater than in the case of the piston expansion, icularly near the top of the chamber.

ı all zones the upward deviations are strongly correlated the positions of the bellows. Although measurements not extend as far as the centre of the outer bellows, it appear as if the dip between the centre two bellows is than that between the outer pairs of bellows, due to the ence of the central strut.

here are two possible explanations for the increased distions with this system; firstly, the bellows are very close he illuminated volume of the chamber; and secondly, velocity vortices might be caused by liquid forced out xpansion from between the bellows' corrugations. It ld thus seem advisable to minimize distortions in any tiple-bellows chamber to fit a sealed floating plate of light construction but high rigidity between the expansion system and the illuminated region.

A small propane bubble chamber can be constructed quickly and at a relatively small cost, and thus it might seem advisable to make a small propane-filled scale model of any projected large hydrogen bubble chamber. A quantitative relationship between the distortions in the two cases would require the scaling to be perfect, although the general form of the distortions would be similar provided that the two chambers were of the same shape.

If it is assumed that compressibility effects, which become of importance only at velocities approaching the speed of sound in the liquid, may be neglected then, for true scaling, Reynolds number, which is the ratio of the inertia to the viscous force, must be identical in the two chambers. The value of Reynolds number is given by lV/v, where l is a characteristic length, V the velocity of the fluid and v the kinematic viscosity.

Propane has a much higher dynamic viscosity than liquid hydrogen, which implies that for perfect scaling the fluid velocity in the model would need to have an exceedingly high value. For example, if the pressure in a proposed hydrogen bubble chamber is to drop to its minimum value in 10 ms, a one-tenth scale model using propane filling would require an expansion time of only 0·07 ms. It is not possible to obtain such high speeds of expansion, and thus perfect scaling becomes feasible only when the model and prototype are operated with similar filling liquids.

ACKNOWLEDGEMENTS

We are grateful to all the other members of the Bubble Chamber Group who have given advice and assistance with this project. We wish to thank Mr. K. Walters for help in running the chamber and processing the films, Messrs. C. Foster and G. Dyke for constructing the chamber body and expansion systems, and the cyclotron crew for maintaining a proton beam of sufficiently low intensity.

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Laboratory and workshop notes

Apparatus for tilting extraction replicas through large angles in the electron microscope

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It has been found that the "selected area" electron diffraction method as normally practised has limitations when used to determine the crystal lattices of individual small plate-like precipitates present in extraction replicas stripped from metal surfaces. This is because, in most electron microscopes, the replicas are held at a fixed angle to the electron beam and so the precipitates, which are generally single crystals, only yield incomplete electron diffraction patterns. The difficulty may be overcome, however, if further patterns are recorded with the replicas tilted at large angles to the electron beam. Two methods for accomplishing this are described, both of which allow sufficient electron diffraction data to be obtained to determine the full crystal lattice of the precipitates. The first uses a new specimen stage of simple design that fits into an electron microscope, type EM3 (by Metropolitan-Vickers Electrical Co. Ltd.) and enables replicas to be continuously tilted from a position perpendicular to the electron beam to a position parallel to the beam. In the second method, replicas are held at predetermined angles to the electron beam by means of small fixed inserts that fit into a standard specimen holder. Inserts of this type may be used in most electron microscopes.

The continuously tilting stage (Fig. 1) comprises a solid brass block (*A*) having a large central hole and carries the usual lateral movement attachments, i.e. two push-rod blocks (*B*) and a pillar (*C*) for holding the return spring. When in position in the electron microscope, the block rests on the top face of the objective lens. A small horizontal hole through the front part of the block near the base hold stainless steel shaft (*D*). One end of the shaft projects i the central hole and is soldered to a shallow $\frac{1}{8}$ in. diame brass cap (*E*) with a diameter of the base of the cap para to, and in line with, the axis of the shaft. The other en soldered to a thin 90° V-shaped brass sector (*F*) arran so that the plane of the sector is perpendicular to the a of the shaft. Longitudinal movement of the shaft is preven by a shoulder on the inner portion of the shaft and by sector on the outer end. The relative orientation of the and sector is such that rotation of the sector from a posit with one edge horizontal (as shown in Fig. 1) to the posit where the other edge is horizontal moves the plane of cap from the horizontal to a near-vertical position.

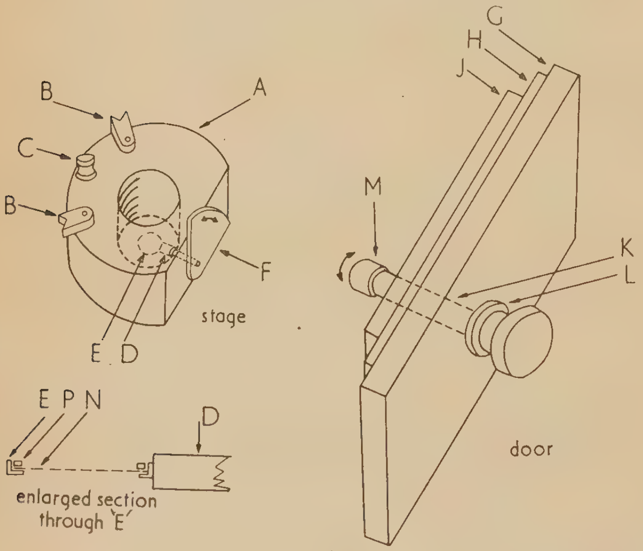
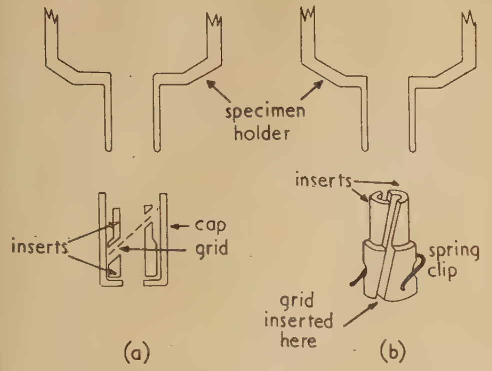


Fig. 1. New stage and door suitable for tilting specimen grids through wide angles in an electron microscope, type EM3 (by Metropolitan-Vickers Electrical Co. Ltd.)

This movement is obtained during operation of the mic scope by the action of a friction-drive shaft which pas through a specimen chamber door specially constructed the purpose (Fig. 1). The door consists of a solid b slab (*G*), on the inner side of which a flat neoprene sheet is held in position by a similarly shaped, but smaller, b plate (*J*). The latter closely fits the opening in the fron the specimen chamber, thus ensuring the same location the door each time it is placed in position. The portio the neoprene sheet surrounding the plate provides the vacu seal. The stainless-steel driving shaft (*K*) is perpendic to the plane of the door, passes through a Wilson vacu seal (*L*, not shown in detail in Fig. 1) and is so positio that the end rests on the curved portion of the ver sector (*F*) of the new stage when the door is in position. ensure intimate contact between the sector and the dr rod, a neoprene sleeve (*M*) is fitted to the end of the This results in a positive, smooth and slip-free rotation the sector. The dimensions of the sector and neopre sleeved shaft can be chosen to give a convenient calibrat constant, e.g. 45° tilt of the replica per revolution of shaft. The extraction replica supported on an electr microscope grid (*N*) is placed in the cap (*E*) and firmly in position by a small brass washer (*P*). The contrast apert is removed from the microscope and the new stage and d fitted. Individual precipitates can be examined as the is progressively tilted, the stage-scanning controls be adjusted to compensate for any lateral movement that occ

Often sufficient patterns can be obtained by recording the extraction replica (*a*) perpendicular, (*b*) at a pre-set an of 45°, and (*c*) at a pre-set angle of 10° to the electron bea This has been achieved with the standard electron-microsc stage and holder by first using the holder in the conventic manner and then placing the grid successively in each of specially constructed inserts that fit into the holder (Fig. Each insert consists of two parts which, when placed togetl sandwich the grid either at 45° [Fig. 2(*a*)] or 10° [Fig. 2 to the longitudinal axis of the specimen holder, and he to the electron beam. The 45° insert fits into a stand $\frac{1}{8}$ in. diameter specimen cap, whilst the 10° insert is together by a spring clip. The insert of Fig. 2(*b*) is sh in solid form rather than section as this illustrates its c struction more clearly. Although inserts could be m with other angles of inclination, the two described here h proved adequate for most examinations.

The continuously tilting stage enables electron diffract patterns to be obtained from individual precipitates incli at various angles to the electron beam, whilst the fixed inse although allowing less latitude in the orientation of ipitates, are simpler and quicker to use. The insert ıod is particularly suitable for those electron microscopes 'e a continuously tilting stage cannot be easily designed fitted. Both methods of examination have been success- applied to several types of plate-like precipitates. Results



g. 2. Specimen holder inserts for examining grids at (*a*) 45°, and (*b*) 10° to the electron beam

erning cementite (Fe_3C) and iron nitride ($Fe_{16}N_2$) pitates have been reported elsewhere.*

ıanks are due to Mr. R. A. Hacking, Director of Research, ermission to publish this paper.

oker, G. R. and Norbury, J. (*J. Iron Steel Inst.*, to be published.)

of a photomultiplier in the flame photometric analysis of substances with emission bands in the red

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[*Note received* 6 *January*, 1959]

ough a number of flame photometers utilize photo- iplier tubes as detectors for radiation at wavelengths of than 5000 Å, alternative detectors have been necessary onger wavelengths on account of the failing sensitivity ıe usual photocathodes. The purpose of this note is to t out that more recently developed photomultipliers with sensitive cathodes can be used to measure the emissions thium, potassium and rubidium, that is, up to 7800 Å. tube used in this laboratory for the purpose is the type 78 TA produced by E.M.I. Electronics Ltd.

ith an apparatus consisting of a Beckman atomizer ıer, a Hilger glass monochromator and the above tube, ıtitative measurements on solutions with 0·1–0·5 μM l (or KCl) per ml. can be made.

Power unit for welding fine wires

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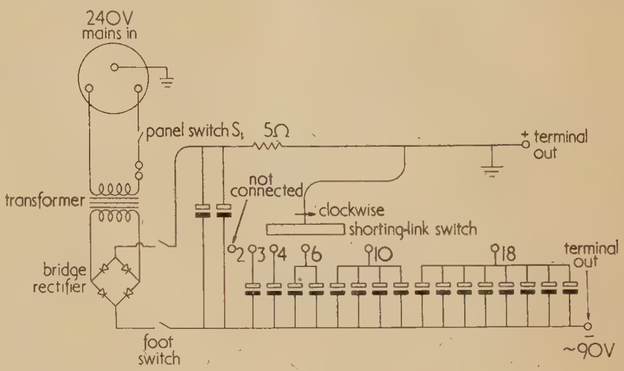
[*Note received* 20 *January*, 1959]

arc welding method had been in use in this laboratory orming beads at the ends of a pair of thermocouple wires. ends of the wires were twisted together and used as one rode, and a carbon rod as the other. This was somewhat similar to the method of Hart and Elkin,† except that the building d.c. main supply, at 230 V with a 300 Ω variable resistance, was used in place of the previous authors' 120 V h.t. battery and 150 Ω variable resistance. The negative side of this supply was earthed at some distance from the building. The arrangement appeared to the author to be a dangerous one. Also the twisted ends were tapped on the carbon rod and the arc quickly extinguished by withdrawal; this process involves skill and it is difficult to repeat a particular type of weld. It was decided to experiment at the lower voltage, using the discharge from a bank of capacitors fed from a source of high internal impedance. A supply of 250 μF, 100 V working, electrolytic capacitors was found to be available.

The circuit evolved is given in the figure. Energy is fed from the capacitors to the welding site through copper leads and the "shorting-link" switch. In the operation of this switch, the wiper makes contact with each successive way in addition to those it has already passed through, so that in position n the wiper is connected to circuit n and also $n-1$, $n-2 \ldots$, and 1; thus the switch can be connected so that as it is moved clockwise more capacitors are brought into circuit in an economical fashion, as all the capacitors in the equipment are in use at the last position. Several poles of the switch are wired in parallel to cut down contact resistance. It would be preferable, however, not to move the selector switch with the power switch S_1 on or with charge on the capacitors, though one is still in use after three years of service without this precaution having been taken. The 5 Ω resistance is inserted to reduce the initial charging current.



Circuit

All capacitors are 250 μF, 100 V working. The numbers 2, 3 . . . 18 refer to the number of capacitors in circuit when the "shorting link switch" is in position 1 . . . n . . . 6.

In use, the output is shorted to remove any remanent charge and the shorting-link switch turned to a likely setting. The mains switch is turned on, the work assembled and steadied. The foot switch is depressed for a few seconds (the charging time constant should be less than a second if the rectifier is in good condition), allowed to open and the weld made. The foot switch prevents the continuous heating which would be provided by the transformer-rectifier source, which was found to have no useful effect, and prevents overloading of these components. Where a carbon rod is used as one electrode, it is preferable to connect it to the negative terminal. A bigger heating effect can be attained with the other polarity, but the weld is then more liable to be carbon contaminated. The positive side of the supply has accordingly been earthed. It is preferable to arrange the work so that single hand manipulation will effect the contact weld. On wires of diameter up to 0·015 in., the shear cut provided by scissors appears to be preferable in cleanliness to the pinch provided by side cutters.

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† Hart, E. D., and Elkin, W. H. *J. Sci. Instrum.*, **23**, p. 17 (1946).

The welding circuit includes the capacitance *C* of the storage capacitors, the resistance *R* of the leads and welding site contact. The time constant of the circuit *CR* will vary with *R*, and so the speed at which energy is transferred from the capacitors to the welding site will vary with *R*. This variation will alter the rate of heating at the site and consequently the amount of metal raised, very temporarily, above the melting point. As the time constant is proportional to *C*, increasing this to increase the total energy available will not entirely compensate in the amount of metal melted for excess *R* in the circuit. In practice, the switch gives a reasonable degree of control over the weld for reasonably short lengths of wire of about 0·015 in. down to 0·002 in. in diameter. With bare wire, a clamp or clip making contact with a comparatively large surface area of the wire can be placed near the end to be welded, so that the length of wire in circuit is limited to a few inches. The energy stored could be varied continuously by inserting a Variac before the transformer, involving extra expense and loss of precision in resetting the level. In this form the time constant would have the maximum value at all energies.

A large number of people have used this device on chromel-alumel, platinum-platinum/rhodium, copper-constantan, iron-constantan, etc., wires of 0·015 to 0·002 in.* diameter. Platinum-platinum/rhodium thermocouple junctions from wire of 0·020 in. diameter have been made inside the glove box. Copper wires have been welded to Nichrome and Pyromic; in one application, two 0·005 in. copper wires were welded to a single 0·004 in. Pyromic wire to form current and potential leads on a small heating element. Butt welds have been made using each wire as an electrode, though the more usual method of forming a junction uses a carbon rod as one electrode. In this wires were at first twisted together, but it was found possible to present the two wires side by side and the pre-weld twisting strain was thereby avoided, resulting in junctions of better life expectancy. A small bridge of weld metal of about the same diameter as the parent wires is preferred to a blob or bead. At first also, an atmosphere of coal gas was arranged for the base metals, but latterly satisfactory welds have been made in air. Wires of copper, chromel, alumel and platinum of diameter ranging from 0·0048 to 0·015 in. have been welded to various rods of thorium, uranium, neptunium and plutonium of 0·040 to 0·250 in. diameter to form current and potential leads, and thermocouple junctions.

Many of the details of experience given above are the result of the author's colleagues' work with this equipment.

* *See also* Kiernan, E. F. *J. Sci. Instrum.*, **32**, p. 321 (1955).

Device for admitting gas at constant rate to vacuum apparatus[†]

By A. D. Osborne,[‡] B.Sc., Ph.D., Division of Pure Chemistry, National Research Council, Ottawa

[*Note received* 26 *January*, 1959]

It is often desirable when studying gas-phase photo-oxidation reactions, to keep the pressure of oxygen constant during the experiment, as this makes the interpretation the results more simple. This means that oxygen must added during the experiment at the same rate as it is be consumed. Manually operated dosers have been used w success* but they are tedious to operate as they invo raising and lowering mercury. This operation becom particularly laborious in experiments requiring very l oxygen pressures (less than 0·2 mm) when more than very small doses of oxygen may be required to keep pressure of oxygen constant within 10–15%. Also, si manual dosers are slow in operation, the light can admitted by a shutter only for short times between do and this introduces considerable inaccuracy in the measu ment of exposure time.

DESIGN

A semi-automatic device has been developed which admit gas at a required rate into a vacuum system. principle, it is a Sprengel pump working in reverse (Fig.

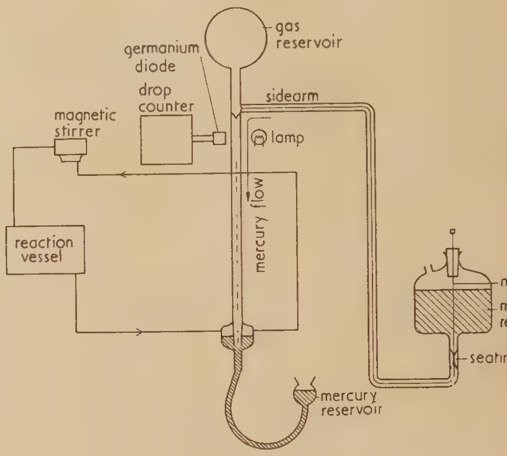


Fig. 1. Schematic diagram of device

The device consists of a vertical length of capillary tub (2 mm inside diameter) with a sidearm at the top thro which mercury can be introduced. At the top, the capill opens into a gas reservoir and, at the bottom, into the react system. Mercury falls from the sidearm in drops, trapp a series of segments of oxygen from the reservoir and carry the segments down into the reaction system. Both of mercury reservoirs have a comparatively large cross-sectio area so that mercury levels remain sensibly the same dur an experiment. At the bottom, the mercury becomes p of a column supported by the atmosphere, while the gas ri to the surface to be carried into the reaction system in stream of reaction mixture circulated by a magnetica driven stirrer. Mercury flow is controlled by a steel-nee seating in a ground constriction in the sidearm. Movem of the needle is controlled with a fine screw (80 turns per so that the desired flow can be obtained. The number drops passing into the system is recorded by a photo-elec counter, which employs a light-sensitive germanium di because of its compactness.

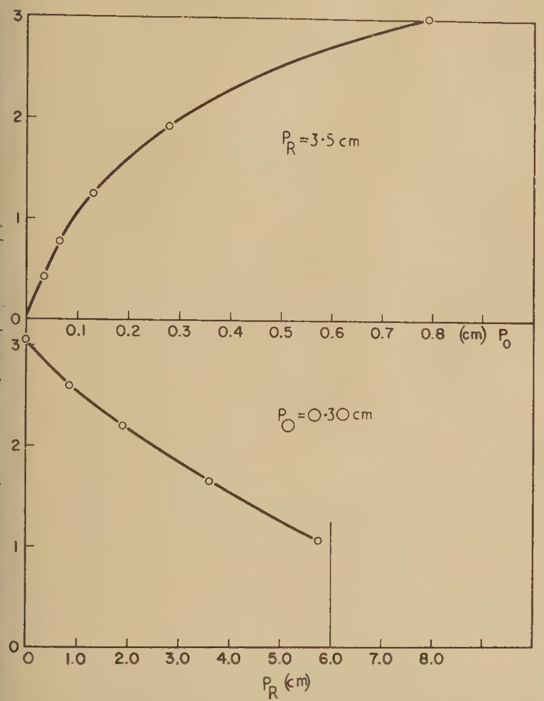
CALIBRATION

The device was calibrated by filling the reaction vessel edetermined pressure P_R with diethyl ketone or carbon ide, which are condensable at −196° C and therefore y separated from oxygen. A certain number of drops xygen was then admitted and the mixture was pumped hrough a trap immersed in liquid nitrogen and the amount xygen was measured in a gas-burette. For given pressures xygen (P_O) in the reservoir, and of condensable gas in the reaction vessel, the mass of oxygen delivered was ortional to the number of drops. The root-mean-square ation of the measurements from linearity was 0·10 μmol. e, in experiments with diethyl ketone, the amount of en consumed during an average experiment is about nol, the doser is accurate to approximately 2% for this m (the burette was accurate to within 0·04 μmol). The ions between amount of oxygen delivered per drop and nd P_O are shown in Fig. 2.

[†] N.R.C. contribution No. 5185.

[‡] National Research Council Post-doctorate Fellow.

* Marcotte, F. B., and Noyes, W. A., Jr. *Disc. Faraday S* **10**, p. 236 (1951).



g. 2. Relation between oxygen delivered and pressures condensable gas in the reaction vessel (P_R) and of oxygen (P_O)

alculation showed that the mass of oxygen per drop ld be proportional to $(L–P_R)P_O$ where L is the length of Sprengel tube—in this case 15 cm. The derivation of formula involves an approximation which is only fied if P_O (mm of mercury) is small compared with the h of a drop of mercury in the tube. In practice, this ot strictly true and the curve of μmol of oxygen per against P_O soon departs from linearity. The curve l of oxygen per drop against P_R follows the theoretical e more closely. The formula predicts that the intercept he curve in the P_R-axis should equal L and that the lition for the doser to work is that L is greater than P_R. ractice, the device ceased to trap gas when P_R approached L.

APPLICATION

s a further test, it was shown that the results of photolysis riments performed with the doser were the same as those obtained with a manual doser. There was no need to interrupt the light during the course of photolysis since oxygen could be admitted at the same rate as it was being consumed. Thus the device makes the experiment simple, automatic and continuous, and operates with greater accuracy than a manual doser.

Reactions at low oxygen pressure are particularly interesting because of their relative simplicity, but so far they have been difficult to study for the practical reasons indicated. The semi-automatic doser offers the possibility of studying such reactions with greater facility and should find a place among the tools already available in this field of research.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. G. Ensell for discussion on the design of the apparatus, Dr. H. V. Carter for discussion on the feasibility of the device and Dr. K. O. Kutschke for his interest in the project.

Method of etching germanium to precise limits

By B. T. Scofield, B.Sc., Mullard Research Laboratories, Salfords, nr. Redhill, Surrey

[*Note received* 5 *March*, 1959]

It is sometimes necessary to make germanium slices accurately to a given thickness. This can be done by starting with a slice of known thickness and etching a measured amount off. This note describes a method of making an accurate measurement of the reduction in thickness during the etching process.

The method is based on that of Lewis and Soper,(1) who describe an apparatus for measuring changes in thickness of colloid layers in water, using the principle of the parallel plate viscometer. A liquid etchant flows through a glass jet of inner radius R_1 and outer radius R_2. One end of the jet is ground to form a flat face perpendicular to the bore. The specimen, in the form of a flat plate, is mounted on a micrometer slide so that it is parallel to the ground jet face and at a distance h away. The pressure needed to force Q cm³/s of liquid of viscosity η poises through the channel formed by the specimen and the jet face is given by(2)

$$P = \frac{6\eta \log_e (R_2/R_1)}{\pi h^3 g} \text{ cm of water}$$

In the present arrangement the specimen was germanium, the flowing liquid was an electrolyte and electrolytic etching was used. The pressure was measured by a water manometer and was maintained constant during etching by slowly moving the specimen towards the jet, thereby keeping h constant. The distance moved is then equal to the thickness of germanium removed, if the etching is uniform over the area opposite to the jet face.

A line diagram of the apparatus is shown in Fig. 1. The electrolyte in the container was maintained at a pressure of 60 lb/in.² using compressed air. It was fed through a capillary of variable length (made from a screw thread) to the jet and the pressure drop across the jet was measured by the manometer. The germanium specimen was soldered to a copper strip which was attached to a micrometer slide. The flow rate was adjusted by the helical capillary so that the pressure indicated by the manometer was about 5 cm of water with the germanium well away from the jet face. In early experiments a metal tube was included in the feed pip to the jet and was used as the cathode connexion. The jet, however, then formed a "virtual cathode,"(3) concentrating the current at the centre and only etching a central depression. This was remedied by wrapping platinum foil around the outer wall of the jet, and using this as the cathode.

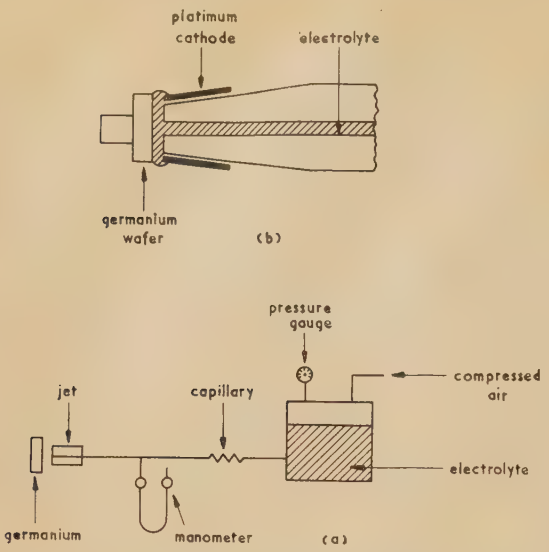


Fig. 1. (*a*) Apparatus for measuring changes in thickness of germanium wafers. (*b*) Enlarged view of jet

A solution of 20% ammonium chloride was used as the electrolyte and the germanium was *p*-type with a resistivity of 1·8 Ωcm. The jet that was used had a bore of 0·6 mm and its external diameter was 3 mm. Fig. 2 shows a graph relating the pressure across the jet to the distance *h*. The germanium specimen was in the form of a wafer, 5 mm square and 150 μ thick. The distance *h* was adjusted to be about 75 μ. Whilst the etching was proceeding, the germanium was moved slowly towards the jet to maintain a constant pressure reading. After etching, the change in thickness of the germanium was measured and compared to the distance traversed during etching. Some results are shown below.

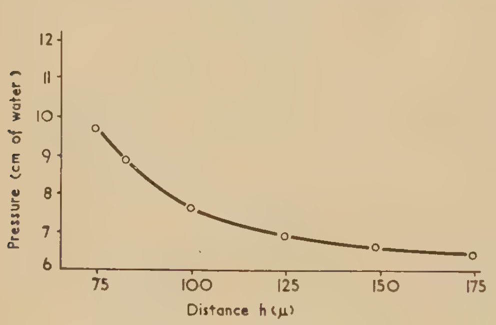


Fig. 2. Pressure across jet related to the distance *h* between the germanium specimen and the jet face

Thickness of germanium removed (μ)	*Distance moved to maintain pressure* (μ)	*Etching current* (*mA*)	*Time* (*min*)
32	32	90	11
29	30	55	18
10	8	25	11

In the above experiments, 20% ammonium chlo solution was used as the electrolyte. This was cho because it: (*a*) does not form bubbles on the germani surface which would affect the pressure reading; (*b*) ha high conductivity to promote a uniform current distributi (*c*) produces a flat surface. If a highly polished surfac required, the above electrolyte is unsatisfactory. Howe 20% sodium hydroxide etches *p*-type germanium to giv "mirror" finish. It will also electropolish *n*-type germani but in this case the surface of the germanium has to illuminated.

ACKNOWLEDGEMENTS

I wish to thank Mr. I. Flinn for drawing attention to paper by Lewis and Soper,(1) Dr. T. B. Watkins for sugges the problem and Dr. M. D. Sturge for helpful discussion

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(2) SCHILLER, L. *Z. Tech. Phys.*, **2**, p. 50 (1921).
(3) UHLIR, A., JR. *Rev. Sci. Instrum.*, **26**, p. 965 (195

Notes on three kinematic constraints

By O. P. T. KANTOROWICZ, Dr.Phil., F.Inst.P., Par
trada Research Station, Wallsend, Northumberland

[*Note received* 11 *March*, 1959]

1. *Figure* 1. A cheap virtual vee-groove for the s free clamping of substantially cylindrical objects (1) o surface of a carrier (2) can be produced by screwing round-headed bolts (3), arranged to occupy the corne a rectangle, into the surface of the carrier (2). The cylin object (1) is forced against the bolt heads (3) by mea the simple strap (4).

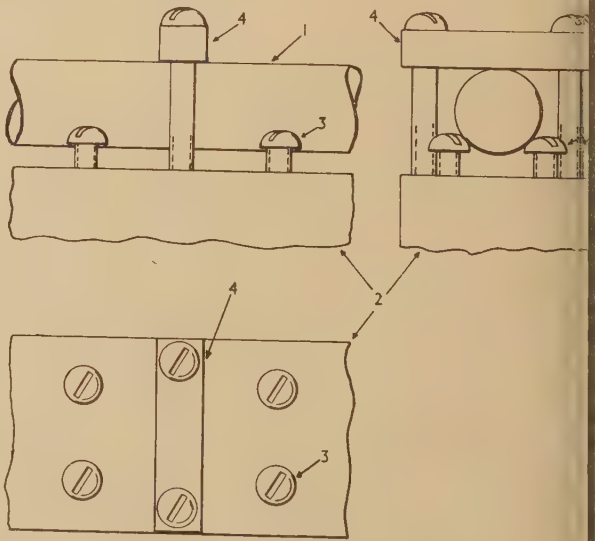

Fig. 1. Virtual vee-groove defined by screw heads

Vee-grooves of this type have been used so far to c cylindrical objects with diameters between ½ and 1 Each size of the arrangement described will accommo a limited range of cylinder diameters (for example, $1\frac{1}{4}$ in.). On the other hand, it allows of short-range stment of direction and position of the axis of the der (1) with respect to the carrier (2) by setting the v heads (3) to a suitable height over the surface of the er.

Figure 2. In a "hole, slot and plane" arrangement of traints, the hole ought ideally to contact a spherically-d foot in three evenly-spaced points with tangent planes the sphere) forming a trihedral hollow. The tangent es usually are inclined to include an angle of between nd 60° with the axis of the foot.

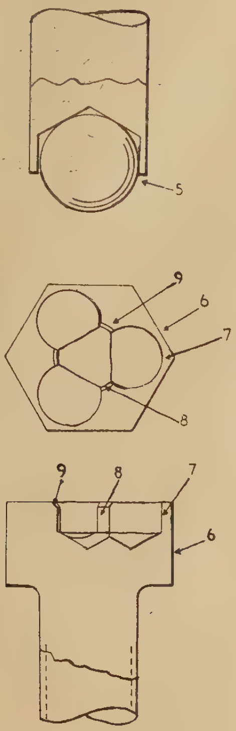

Fig. 2. Formation of trihedral hollow

soft materials, like brass, small hollows can be formed neans of a trihedral punch indenting the edge at the th of a drilled hole. In tougher materials, larger hollows be formed by dressing the edge with a file. It is, how- not an easy matter to convey by engineering drawings lesigner's intention to workshop personnel not familiar kinematic designs. The design described here has been for contacts with $\frac{3}{4}$ in. diameter ball-bearings and formed steel bolt head which was subsequently hardened. Such heads are used to form hard and roughly adjustable ons which are screwed into large structures, like turbine gs, to define instrument locations.

Fig. 2, the diameter of the sphere (5), which forms a of an instrument, is taken as unit. Into the flat top face e button (6) are drilled three equidistant holes (7) with eter $\frac{5}{8}$ of Unit (U) on a pitch circle with diameter $\frac{7}{8}$ U to th of about $\frac{1}{2}$ U. A fourth hole (8) of diameter $\frac{5}{8}$ U is drilled centrally between holes (7). Finally, a ball-ng of unit diameter is placed centrally over the centre (8) and given a sharp tap with a hammer. The initially edges of the three ridges between holes (7) are thereby ically deformed into a spherical seat (9) for the sphere (5). button is subsequently case-hardened. (If standard B.S.F. bolts are used to form the button—high tensile steel ones may be adequately hard—the bolt diameter is 1 U.)

Darby* has described a similar design. The present one is presumably somewhat stronger, but might become more readily disengaged if the instrument were knocked accidentally. Where this danger exists, both designs can be improved upon by surrounding the area into which the holes are drilled with a skirt. In the present design, this could be done by drilling or boring concentric with the central hole a larger one, of a diameter larger than unity, say $1\frac{1}{16}$ U to a depth of about $\frac{1}{4}$ U and by forming the spherical seats (9) at the bottom of this larger hole.

3. *Figures* 3 *and* 4. In a contact which is to constrain a body only in respect of a single degree of freedom, the body must be free to move sideways a little and to rotate through small angles without being impeded by friction. Lightly-built instruments otherwise are likely to distort fortuitously, either when settling down on their constraints or in consequence of working stresses or of thermal strains.

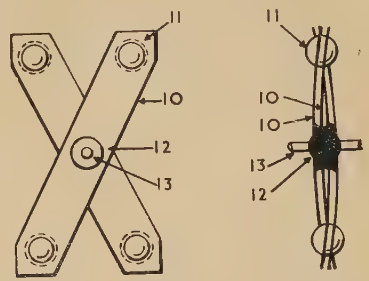

Fig. 3. Ball-bearing retaining cage for an antifriction shoe

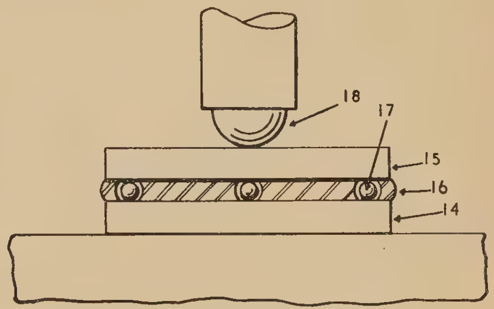

Fig. 4. Retention of ball-bearings between plane surfaces by a perforated sheet of sorbo rubber

In a recent example of a large vee-block with end constraint, this difficulty was overcome by interposing at each contact a "shoe", that is, a small hardened and ground-steel plate, floating on a number of ball-bearings, which were retained in light cages. These are shown diagrammatically in Fig. 3.

The cage was formed from pairs of thin leaves (10) of spring-steel tape (Cambridge Torsiograph tape 0·0045 in. thick) cemented together in the centre with "Bostik". The ball-bearings (11) were snapped into punched holes at the free ends of the tapes and similar holes accommodated a central bead (12) of Bostik. The cage was held captive by a pin (13) through the bead (12). The bead was of lesser bulk than would appear from the diagrammatic side view, and therefore of sufficient flexibility to allow of relative motion of pin (13) and the assembly.

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* Darby, J. F. *J. Sci. Instrum.*, **31**, p. 224 (1954). Reprinted, Laboratory and Workshop Notes 1953–1955, p. 58 ff.

More convenient was a later shape (Fig. 4) in which a sandwich was formed of two hardened and ground-steel plates (14 and 15), separated by a perforated layer of sorbo rubber (16) which, in its free state, was $\frac{1}{4}$ in. thick and which was stuck between the steel plates with Bostik. The perforations, five in all, at the corners of a rectangle and its centre, were of about $\frac{1}{4}$ in. diameter, and each contained a $\frac{3}{16}$ in. diameter ball-bearing (17).

When this sandwich was interposed between the instrument foot (18) and its support (19), the sorbo rubber was compressed until the ball-bearings (17) supported the load. The steel plates (14 and 15) could, however, be translated smoothly with respect to each other by about $\frac{1}{8}$ in. and rotated a few degrees about an axis normal to the steel plates. The sandwich proved itself a robust self-contained unit and, the sorbo rubber excluding gritty dust from the contact, remained of very low friction.

I acknowledge permission from the Director of Pametrada Research Station to publish this note, and the intimate co-operation of my former colleague, Mr. J. A. Binns, in the development of the anti-friction devices.

Automatic constant level device for liquid air

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[*Note received* 1 *May*, 1959]

It is often necessary to maintain the level of liquid air constant in Dewars or cold traps and a number of devices that do this automatically have been described.$^{(1-8)}$ In this note we describe such a device which has the advantages of simplicity, ruggedness, and a minimum of moving parts.

The general layout is shown in Fig. 1. The fall of liquid air level in the trap is detected by a thermistor T whose resistance is about 10 MΩ when touching the liquid surface, and about 2 kΩ when clear of the surface. The thermistor is connected in series with the coil L of a magnetically operated valve and a d.c. supply, and it thus controls the coil current directly.

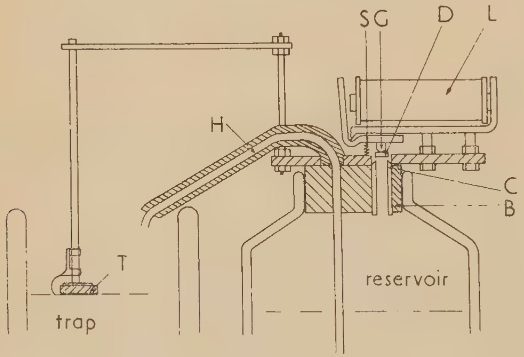

Fig. 1. Constant level device

The reservoir Dewar of one quart capacity is closed by a rubber stopper B surmounted by a platform. The liquid air in the reservoir evaporates slowly and normally escapes through the short glass tube C. The upper end of C is ground to a 45° bevel so that the tube terminates in a sharp edge which just enters a hole in the platform. A neopr
disk D lies in the recess so formed on top of the tube and
escaping air is easily able to lift it. However, if the coi
energized a plunger G on its armature presses the disk do
thus sealing the tube. As a result the pressure in the reserv
rises, forcing liquid air through the lagged siphon tube
to top up the level. The upward movement of the disk
limited by the plunger when the coil is not energized,
armature being held against its stop by a light coil spring

As no available standard thermistor was found to h
suitable characteristics, a disk 1/32 in. thick by $\frac{1}{4}$ in.
diameter was cut from a Mullard VA1005 thermistor, th
dimensions being arrived at experimentally. The clip wh
holds the thermistor also makes electrical contact *via*
evaporated silver film on each plane surface.

Under settled conditions there is little difference betw
the temperature of the liquid air and that of the reg
immediately above the surface. Hence if the thermistor is
act effectively as a switch, heat must be supplied to it a
fairly constant rate; the temperature changes in it are t
the result of the different rates of cooling in liquid and
In practice it is found that the electrical leads conduct eno
heat to the thermistor if they are not too thin, and the
of response is further enhanced by resistive heating
the thermistor. But if thermal conduction and resis
heating are excessive the thermistor will not cut off wh
immersed.

The electrical circuit is shown in Fig. 2. When
thermistor T is immersed it effectively governs the cur

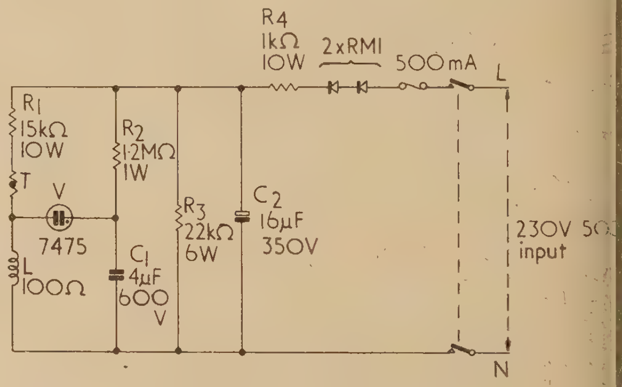

Fig. 2. Electrical circuit

through the solenoid L, and when it is above the surface
current is limited to a suitable value by R_1 (15 kΩ).
charges from the d.c. supply *via* R_2 and at about 3 s interv
discharges rapidly through the Mullard 7475 gas discha
tube V and solenoid L, thus momentarily operating
magnetic valve at an overcurrent. Thus positive va
closure is ensured despite relatively slow changes in circ
resistance. Also the valve is operated by the first cur
pulse appearing after the solenoid direct current has attai
the minimum holding value. Since the latter is considera
lower than the pull-in current, the electrical backlash us
to magnetically-operated devices is practically eliminated

This device is able to maintain a surface level constant
within one to two millimetres. In its present use it is able
top up a well-insulated cold trap for about sixteen ho
without attention. If a larger reservoir were to be used
auxiliary means of raising the pressure would be necessa
because the response time increases as the level falls in
reservoir.

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Pump for circulating gases

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[*Note received* 20 *April*, 1959]

ımp was needed to draw air samples through Drechsel es at various speeds in the range 2 l./h to 10 l./h, and al commercially available pumps were tried. Most of were driven by electric motors which would operate actorily at one speed only, and the speed of pumping to be adjusted by throttling down the gas stream. This unsatisfactory because dust and moisture affected the tle aperture and altered the pumping speed. It was d that a variable speed pump could be made as follows of cheap and easily obtainable materials.

ie drawing shows the method of construction; *A* and *B* ubber bungs (size 1¼ in.) with one hole in each. In one a tightly fitting bolt *D* is inserted with its head sunk in ubber; *C* is a short length of bicycle inner tube which is tly stretched when a bung is inserted in it. The outer ces of the bungs and the inner surface of the tube are ied with solvent, anointed with rubber solution, and ed together leaving a 2 or 3 mm gap between the bungs. tube is then bound on to the bungs with adhesive tape. bung *A* is pushed a glass T-piece which connects with two one-way valves *EE′*. To make a valve, two small rectangular pieces of inner tube (*L*, *M*) 1 × ½ in., are cut, cleaned with solvent and coated with rubber solution. One-third of the area of one rectangle is covered with a strip of paper *N*, and when the solution is tacky the two pieces of rubber are pressed together. When the solution has set, the paper strip is extracted and the valve is slipped over the end of a glass tube and bound on with several turns of a rubber band. The two valves are mounted in the glass T-piece as shown. Bung *A* is firmly held in a suitable clamp. Bolt *D* is connected to a rod as shown, although a flexible coupling is not necessary. The rod is screwed into a brass ring *K* into which a ball bearing is inserted. This in turn is pressed on to a spindle *F*, the eccentricity of which relative to *H* can be adjusted by screw *G*. A suitable amplitude of motion for the spindle is 1½ to 2½ mm, and by altering this value different speeds of pumping can be obtained. Larger or smaller bungs and tubes could be used to cover other ranges of pumping speed. The base of spindle *F* moves in a slot in a circular plate *J* with a sleeve which is locked on the spindle *H* of a small fractional h.p. electric motor. Spindle *H* is driven through a reducing gear at 200–250 rev/min. For taking simultaneous samples it has been found convenient to screw another connecting rod into ring *K* at the opposite side and drive another similar pump.

The author wishes to express his thanks to Prof. E. G. Cox for the facilities for making and testing the pump.

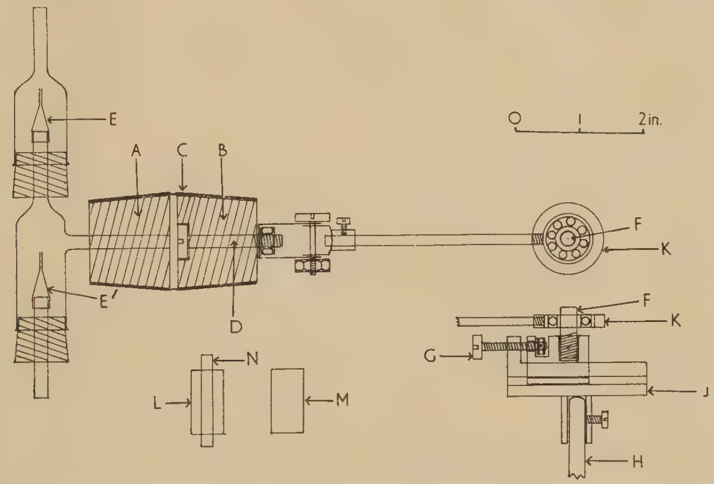

Diagram showing method of construction of pump for circulating gases

Collection of chromatographic fractions in a mass spectrometer sample system

By J. H. Beynon, B.Sc., F.Inst.P., R. A. Saunders, B.Sc., Grad.Inst.P., and A. E. Williams, Grad.Inst.P., Imperial Chemical Industries Limited, Dyestuffs Division, Blackley, Manchester 9

[*Paper received* 23 *April*, 1959]

The techniques of mass spectrometry and gas chromatography are applicable to the analysis of a variety of organic compounds and are, to a large extent, complementary. Any compound which is sufficiently volatile to pass through a gas chromatograph column can be analysed by mass spectrometry and *vice versa*. It is a logical step to use both techniques in combination on a single problem.

This has previously been done in two ways. In the first of these the sample is separated into fractions in the gas chromatograph and the various fractions collected and individually transferred to the mass spectrometer for indentification.(1–4) This method has the disadvantage that a complicated collector system is necessary and there is the danger that samples (especially in very small amounts) will be lost during the collection and transfer.

In the second method the gas stream eluted from the column is analysed continuously by a rapid-scanning mass spectrometer.(5–7) This has the disadvantages that sensitivity is sacrificed due to the short time constants necessary in the detecting circuits, and that the sample is diluted by carrier gas and the amount of sample in the sample system at any instant is limited by this fact.

A third method which has not previously been described, but which combines simplicity with high sensitivity is to connect the chromatograph to the mass spectrometer and to collect the individual fractions, in turn, in the mass spectrometer sample-handling system. The arrangement shown in Fig. 1 has been successfully used to do this. High vacuum taps T_1, T_2 and T_3 form part of the usual sample-handling system and T_4 is the tap through which the carrier gas is pumped. The taps can be of the metal needle-type to operate at elevated temperatures, if desired.

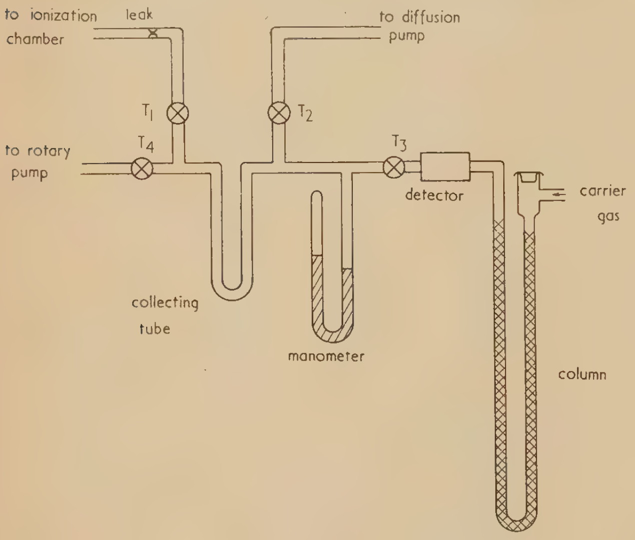

Fig. 1. Arrangement of apparatus

Initially T_1 and T_2 are closed and T_3 and T_4 opened, the chromatograph being then separated from the mass spectrometer. With carrier gas flowing through the column, a sample is injected through the serum cap in the normal way. As soon as a sample is detected leaving the column, a Dewar containing liquid nitrogen is placed around the collecting tube. When the first fraction has been condensed, T_3 and T_4 are closed, thus cutting off the chromatograph. T_2 is then opened and the volume enclosed by the taps, including the collecting tube, is completely evacuated. When this has been accomplished, the liquid nitrogen is removed, T_2 is closed and the sample is allowed to evaporate. It is then admitted, *via* T_1, to the ionization chamber of the mass spectrometer. The mass spectrum of this fraction is recorded, and when this has been completed the initial conditions are restored with T_1 and T_2 closed and T_3 and T_4 open.

The chromatograph is then back in operation, the distribution of the mixture remaining within the column having been "frozen" during the performance of the ab operations.(8) It is necessary that the detector used sho be of a type which does not show a long-term drift when gas flow is switched on. The catharometer detector is very suitable for this application and a type such as the β- detector is better employed. The next component to le the column is collected as before and the operation descri above repeated. This whole procedure is then carried as each component emerges from the column until all various substances have been collected and their m spectra recorded.

The above procedure is based on the assumption that e component has been fully resolved by the chromatograph that no overlapping of the peaks occurs. If, however, peaks do overlap, as shown in Fig. 2, it is a relatively e

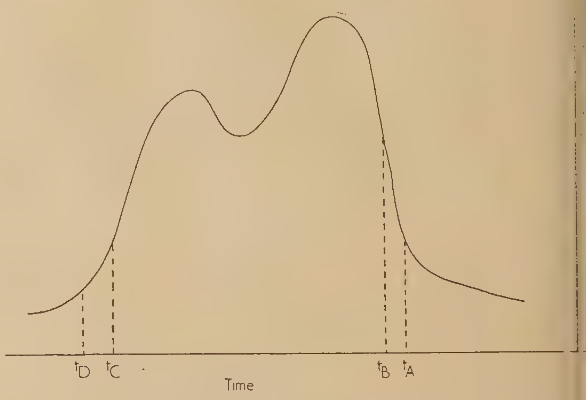

Fig. 2. Separation of overlapping peaks by collecti samples within narrow time limits

matter to separate the two components. In this case samples are collected during the time intervals t_A to t_B t_C to t_D, and thus the two components are admitted to mass spectrometer with little interference from each ot In this case a foreknowledge of the chromatogram is a g advantage and it would, therefore, be necessary to carry a preliminary separation using the chromatograph alone.

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Cap-and-cup mercury vacuum seal

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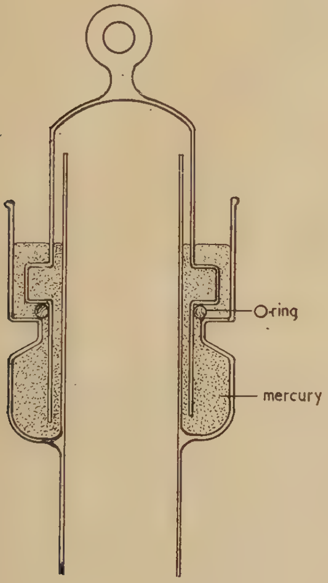
Caithness

ote first received 23 *March, and in final form* 9 *May,* 1959]

joint to be described was developed for a vacuum ratus which was to be operated by remote control, but likely to have applications to other apparatus. Cone-socket joints sealed with grease or wax were rejected se of the difficulty in application of grease or wax by te control, and possible difficulty in separation. Dry -and-socket joints sealed with mercury are unsuitable se of difficulty in separation.

overcome these objections a mercury-sealed O-ring has been designed. The joint is illustrated in the figure, consists of a cap in a mercury cup, with an elastomer ng seal. Only mercury and glass are exposed to vacuum, it is impossible for the O-ring to outgas into the evacuated m.



Cap-and-cup mercury vacuum seal

hen the apparatus is at atmospheric pressure the cap s on the mercury, and may easily be lifted off. The ng used is a close fit on the cap, and lifts off with it. cuating the apparatus causes the cap to sink until the ng meets its seat, thereby forming a seal. On readmitting o the apparatus the extended central tube prevents the from tilting unduly.

version of the joint is in use which, on removing the cap, nits access to a number of small-bore tubes through which rate samples may be loaded into individual sample bays vacuum fusion apparatus. Another version has a cap l with an optical flat. This is used in conjunction with ism for viewing an evacuated furnace tube, and permits cleaning of the inside face of the optical flat.

ne assembly is constructed of Pyrex. The cup O-ring was turned on a glass-worker's lathe, using the edge of rbon flat as a former. During this operation the flat was y clamped to prevent any lateral movement occurring on application of air pressure inside the cup. Provided that the glass is of even wall-thickness, the resultant seat is satisfactory without any grinding.

The cap was also lathe-turned. On the grounds of sturdiness, turning down and thickening the narrower portions from large-diameter tubing was preferred to blowing the wider section from narrow tubing. About 1 mm clearance was allowed between the inner edge of the cup seat and the outside of the cap stem. Joints of about 2 in. seat diameter have been fabricated in this manner. Smaller joints have not been constructed, but these would possibly require light grinding of the seats.

The joint provides a simple means of sealing or opening a vacuum system without the use of heat or complicated movements. It is suitable for remote operation and glove-box work.

Joints of this type have been used in a vacuum fusion apparatus at Dounreay. Their operation has proved satisfactory over a period of about a year.

A provisional patent application has been filed covering this joint.*

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* Brit. Pat. Appln. 570/59.

Comparator for X-ray spectrum films

By C. F. Smith, F.R.P.S., Farnham Common, Bucks.

[*Note received* 2 *April,* 1959]

In the comparison of X-ray spectra on film the usual method is to lay one film on the other to bring the spectra into coincidence or juxtaposition. Because, in general, the lines are too diffuse for magnification, it suffices to place the films on a simple light box for examination. However, this method is not very satisfactory if a number of spectra are photographed close together when very faint lines are present, or if the films are wet from development. Sometimes a mirror is used to obtain the required juxtaposition of spectra, but this entails a dividing line remote from the focal plane, and an awkward reversal.

The comparator for X-ray films described here, and illustrated in Figs. 1 and 2, is designed for continuous work,

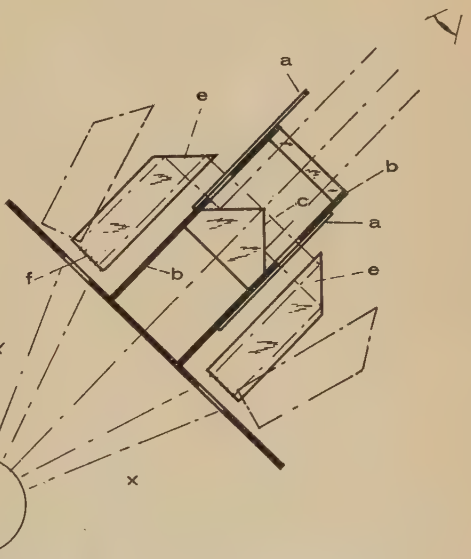


Fig. 1. Schematic diagram of comparator

and enables the comparison of one spectrum with another to be made whatever its position on the film, with a dividing line very near to the focal plane, and an absence of parallax. The films *a* (shown in Fig. 1) are held by light clips in guides against the slotted plates *b* and are adjusted so as to bring the selected spectra into position on the slots. The images reflected in the mirror surfaces *c*, which extend the full length of the film, lie in the same plane, so that there is no parallax. The sharply defined edge of the roof forms a good dividing line, quite near to the focal plane. The films are illuminated by two 15 W lamps *d*, by means of the prismatic plates *e*, the surfaces *f* of which are ground so as to provide diffusion. (The plates can be hinged out of the way so as to give easy access to the films for loading or removal.)

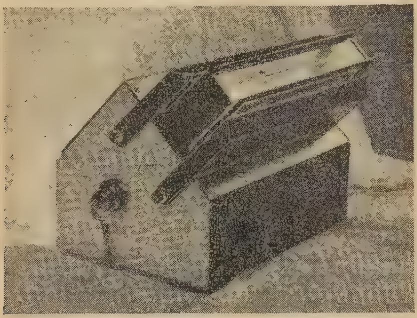


Fig. 2. Photograph of comparator

The instrument is suitable for films of standard sizes, and, in the first instance, is arranged for films used on the Nonius-Guinier Quadruple Camera (by N.V. Nederlandsche Röntgen-Apparatenfabriek), which measure 184 × 43 mm and which usually accommodate four spectra, 8 mm wide. For spectra which can tolerate some magnification, a low-power eyepiece or magnifying lens can be fitted near to the upper glass plate, which acts as a dust cover.

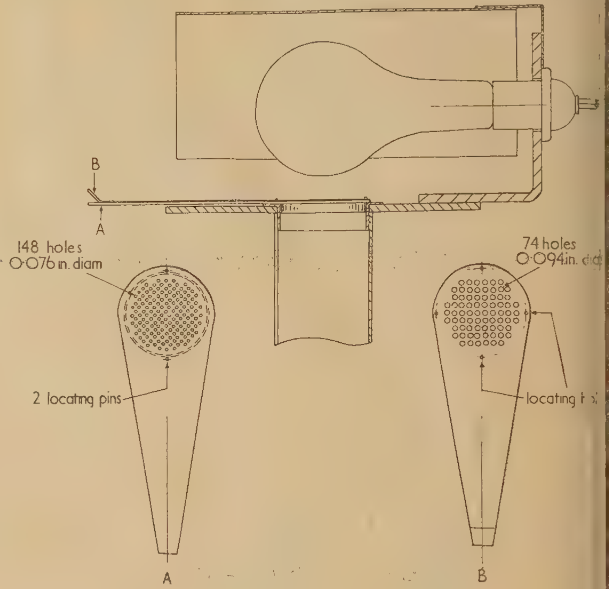
New absolute wedge-calibration method for the Dobson ozone spectrophotometer

By J. P. Funk, Dr.Phil., C.S.I.R.O. Division of Meteorological Physics, Aspendale, Australia

[*Note received* 14 *April*, 1959]

As far as is known, the only method used for obtaining an absolute wedge-calibration of the Dobson Spectrophotometer is the so-called "two-lamp" method.* † This method is time-consuming because of the difficulty in keeping the two lamps at equal brightness. Furthermore, because of the insufficient light available, the thick part of the wedge can be covered and, in the thinner part, a comparatively h scatter of readings is experienced. The method descri here is both quick and accurate and, because it easily cov the full range of the wedge, makes the use of the rhodi plate unnecessary.

As shown in the figure, a perforated plate with 148 ho 0·076 in. diameter, is placed on top of the tubular fitting the standard-lamp holder. A second plate, having half



Perforated plates and mounting

number of holes of slightly larger diameter and suita placed, is mounted so as to obscure every second hole in bottom plate. On rotating it by 90°, these holes beco uncovered, while the others are now obscured.

The calibration procedure is essentially the same as for "two-lamp" method. First, the top plate is removed, an reading is taken through the full number of holes. Thi followed by two readings taken with the top plate repla through alternate sets of holes. Then, another readin taken through the full number of holes. For the gre part of the wedge, the standard lamp is sufficient. Only the thick part of the wedge need it be replaced by a stro source, for example, a "Photolita" (by Philips), under- at 200 V.

It is not difficult, by careful construction, to ensure the readings through alternate sets of holes do not di significantly. To reduce instrumental warming-up, tubing of 2 mm bore is coiled around the internal lamp cas and water circulated through it. The above calibrat method would, in principle, be suitable for any double-be spectrophotometer using a wedge in the reference beam.

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* *Ozone spectrophotometer adjustment and calibration manual* (London: Beck, 1956), p. 29.

† Dobson, G. M. B. *Ann. Int. Geophys. Year*, **5**, p. 101 (1957).

Correspondence

Simple method for finding the ratio of surface tension to viscosity of a liquid

A novel and accurate method for finding the ratio of the surface tension of a liquid to its coefficient of viscosity, T/η, has been developed. The apparatus, Fig. 1, consists of a capillary tube *AB* of length *l*, fixed alongside a scale a suitable inclination θ to the horizontal and a water ma meter *MN*. The lower end of the tube is kept immerse the liquid with the bore of the tube just below the surf

The liquid is drawn into the tube by surface tensi

, but the motion of the ever-increasing thread of liquid arded by viscous forces acting on it and on the air n in the tube in front of the meniscus. In addition, solved component of the weight of the thread retards otion. At a given instant the liquid thread of length x e column of air in the tube of length $(l - x)$ are moving a velocity v. The surface tensional force pulling the meniscus forward is $2\pi rT\cos\alpha$, where α is the angle tact and r is the radius of the bore of the tube. The ed component of the weight of the thread acting down be is $\pi r^2 x\rho g\sin\theta$ where ρ is the density of the liquid. expression for the viscous drag on the thread of liquid ly obtained from conditions of steady flow given by ille's formula

$$Q = \pi pr^4/8l\eta \tag{1}$$

Q is the volume of liquid that flows per second across ction of the tube and p is the pressure difference between ds of the tube urging the thread of liquid to move with city v. Since the flow is steady the viscous drag on the thread of length l is balanced by the force $\pi r^2 p$ acting Obviously

$$Q = \pi r^2 v \tag{2}$$

equations (1) and (2) it follows that the viscous drag

$$\pi r^2 p = 8\pi l\eta v.$$

f a thread of liquid moves through a capillary tube with y v the viscous drag on it per unit length is $8\pi\eta v$. alogy, the viscous drag on an air column moving in pillary tube with velocity v is $8\pi\eta_1 v$ per unit length, η_1 is the coefficient of viscosity of air.

lying the above results to the motion of the liquid in clined capillary tube under consideration, the viscous n the thread of length x is $8\pi\eta vx$ and on the air column nt of the meniscus is $8\pi\eta_1 v(l - x)$. Now the thread a distance δx and the work done by the force of e tension minus that done against the viscous forces gainst the weight of the thread should be equal to the energy of the added mass of liquid.

ce

$$\cos\alpha - \pi r^2 x\rho g\sin\theta - 8\pi\eta vx - 8\pi\eta_1 v(l - x)\}\delta x = \tfrac{1}{2}(\pi r^2\delta x\rho)v^2$$

ng by $8\pi\eta x\delta x$ and rearranging the terms

$$\frac{\cos\alpha}{4\eta x} - \frac{r^2\rho g\sin\theta}{8\eta} - \frac{r^2v^2\rho}{16\eta x} = v\left\{1 + \frac{\eta_1}{\eta}\frac{(l - x)}{x}\right\}$$

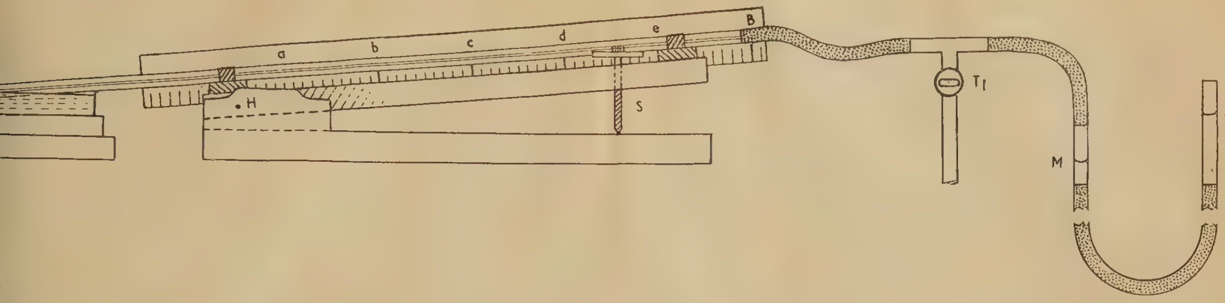

Fig. 1. Instrument to measure the rate of ascent of a liquid, in a capillary tube kept at a small inclination to the horizontal

AB, capillary tube kept on an inclined plane which can be tilted by turning screw *S* about hinge *H*. *MN*, manometer, the limbs of which can be raised or lowered.

or

$$m/x - K - C = v(1 + n) \tag{3}$$

The term C is less than $0{\cdot}1\%$ of m/x if the liquid is water and the radius of the tube is $0{\cdot}5$ mm, and the fraction n is less than $0{\cdot}02$ when the liquid thread has a length greater than half the length of the tube. Hence we are justified in omitting the terms C and n and write equation (3) as

$$m/x - K = v \tag{4}$$

Equation (4) shows that the plot of v against $1/x$ must be a straight line and that the slope of this line is m. If we can note the time when the meniscus reaches known points b, c, d, etc., distributed at equal distances apart in the tube, a curve can be drawn representing the distance x against time, and the velocity corresponding to various values of x can be found from the slope of the curve at those values of x. The values of v are thus found for various values of x. The plot of v against $1/x$ gives a straight line (see curves in Fig. 2),

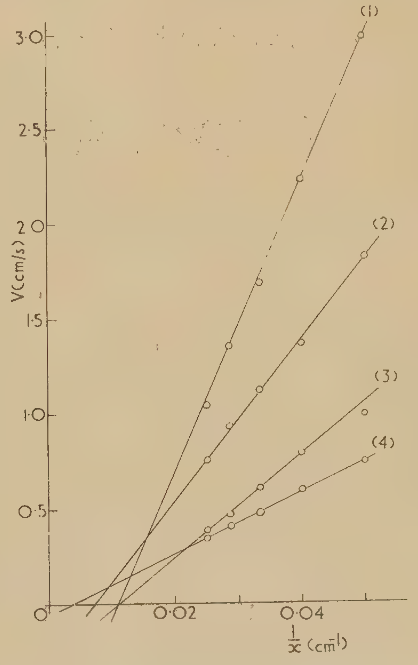

Fig. 2. Curves representing variation of velocity v with reciprocal of the length of the liquid thread $1/x$

Curve (1) water; curve (2) benzene; curve (3) carbon tetrachloride; curve (4) nitrobenzene.

the slope of which yields the value of $m = rT\cos\alpha/4\eta$, and therefore the ratio T/η.

The method indicated above has been applied to a number of liquids. Keeping the tap T_1 closed, the limbs of the water manometer are raised or lowered till the meniscus of the liquid thread is very near *A*. On opening the tap the liquid meniscus moves forward and a stopwatch is started when it passes the division *b* on the scale; the watch is stopped when the meniscus passes the division *c* and thus the time t_1 is determined. Observations are repeated by bringing the meniscus back to the end *A* and the average value of t_1 is found. Similarly, the time t_2 for the meniscus to move from *b* to *d* and the time t_3 to move from *b* to *e*, etc., are found. We thus get sufficient data to draw the curve representing the distance *x* of the meniscus from the end *A* and the time *t*, from which it is easy to find the velocity corresponding to various values of *x*.

In Table 1 are given the values of *v* and $1/x$ for various liquids which wet glass, i.e. those having angle of contact zero. The ratio T/η is calculated and given in Table 2.

Table 1. *Variation of velocity v with reciprocal of the length of the liquid thread* $1/x$

Reciprocal of length of thread $1/x(cm^{-1})$	*Velocity v (cm/s)*			
	Water	*Benzene*	*Carbon tetrachloride*	*Nitro-benzene*
0·05	2·991	1·83	1·003	0·7420
0·04	2·229	1·37	0·7927	0·5869
0·033	1·693	1·124	0·6153	0·4742
0·0286	1·348	0·9401	0·4704	0·4062
0·025	1·035	0·7561	0·3943	0·3417

Table 2. *Slope of curve representing velocity and recipr of the length of the thread, and* T/η *calculated for var liquids*

Liquid	*Slope m*	*Radius of tube (cm)*	T/η *from experiment*	*Temperature (°C)*	*T/ fro tab*
Water	76·35	0·03605	8472	27·5	84
Benzene	43·14	0·03605	4787	28·5	48
Carbon tetrachloride	27·17	0·03605	3018	28·5	29
Nitro-benzene	15·99	0·02463	2596	30·0	25

The expression for *m* contains only the first power of the radius of the tube, and hence the error in the final result is of the same percentage as the error in the measurer of *r*. The usual Poiseuille's method of finding the abso viscosity of a liquid using the formula (1) involves an in the value of η, which is four times as great as that in measurement of *r*.

Now η can be calculated from the ratio T/η knowing value of *T*. The value of *r* to be used is the average ra of the tube, which fortunately can be more accurately mined than the radius at a particular point. The capi rise method of measuring surface tension needs the mination of the radius of the tube at the meniscus. It be noted that as the thread moves forwards the men renews itself and so the surface is ever fresh. Hence determine η by other means, this new method will gi very accurate value of surface tension.

The intercept of the graph representing *v* and $1/x$ o axis representing *v* gives the term *K* of the equatio Since $K = r^2\rho g\sin\theta/8\eta$ an approximate value of η can be found from a knowledge of the inclination θ of the

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G. M. Sreekanta
N. Rajaram
C. K. Ponnappan
[29 *December*, 19

NOTES AND NEWS

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or imp products. The Institute of Physics assumes no responsibility for the statements given below: information for these has taken from literature supplied.

Microfocus X-ray unit. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

The microfocus and semi-microfocus generator provides a brilliant fine-line or spot focus for X-ray diffraction work and microradiography. Used with suitable cameras, it makes for much shorter exposures than are usually required. The cubicle housing all the pumping equipment, power supplies, and controls, has a large flat table-top, the only protrusion above which is the slender X-ray tube itself. There is plenty of room on the table-top for cameras and other equipment, and so little obstruction to diffractometers that they can be used for work at very high angles of 2θ. Two types of X-ray tube, and two types of electron gun usable with both of them, offer a wide choice of focus conditions.

The X-ray tube of either of the two available types is a cylindrical Monel-metal evacuation pipe (through which the anode rises centrally) terminating at its upper end in a Monel-metal block, which supports the electron gun and is bor take the target and to provide windows for the X-ray b

In one type of tube, the block is mounted horizonta top of the evacuation pipe and the electron beam is horiz This form gives *two* horizontal beams viewed at an ang 6° to the target face. In the other, the block is mo vertically downwards to the target. This form gives X-ray beams, each rising at an angle of 6° from the zontal face of the target. All the windows are $10\frac{1}{2}$ in. the table-top and are fitted with shutters to provide protection against stray radiation.

Two types of electron gun may be fitted into one e the Monel-block on the X-ray tube. One is a simpl with a line-filament cathode. This gun gives a focal measuring 100 μ by 1·4 mm, which, when viewed at an of 6°, is foreshortened either to an apparent focal spot 100 μ across or to an apparent fine-line focus 1·4 mm

0 μ wide. With this gun, the optimum loading on a r target is 3 mA at 50 kV/d.c., which results in an loaded focal spot giving a beam free from aberrations oout six times as brilliant as that from a normal sealed- ffraction tube. A particular feature of the gun is its size. It extends only to 10 mm from the end of the tube, or 30 mm from the window, so that movement diffractometer is restricted as little as possible. The d is a microfocus gun of the Ehrenberg-and-Spear . This gun is like that of the earlier Hilger microfocus tube, and is interchangeable with the simple gun. The ter of the focal spot is approximately 40 microns, the um loading being 400 μA at 50 kV/d.c. This gun can e used with a line filament and focusing cap to give a ocus similar to that provided by the simple gun.

anode is a double copper tube—one tube within er—so that cooling oil can be pumped through it. It itioned centrally in the vertical evacuation pipe and held in place near its top end by a spider-like insulator, is not big enough to impede evacuation appreciably. acuum seal is demountable and the main insulator at ottom so made that the anode can be withdrawn when ary.

face of the anode tip is horizontal in the vertical tube, ertical in the horizontal tube, and several interchange- argets are available, all inserted and removed easily a special tool provided with the generator. Targets of llowing materials are at present available: copper, iron, ium, cobalt, nickel, silver (molybdenum and tungsten cial order).

y good resolution, it is stated, is obtained when using ctometers with the microfocus tube. With a receiving f 0·1 mm, the resolution is somewhat better than that a sealed tube with a focus measuring 10 by 1 mm. The ition can be improved by a further factor of 2 by using 5 mm receiving slit. The small size of the tube means diffractometer can be used up to very high angles of 2θ.

n antimonide cell. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

w type of photoconductive cell designed for high-speed red spectroscopy, including the analysis of gases, has introduced. The cell (type ORP10) has an uncooled m antimonide element and is sensitive to infra-red tions of wavelengths up to 8 μ.

e indium antimonide cell has a wider response range in nfra-red region than any other type of detector operating om temperatures, with the exception of thermal devices as the bolometer and thermopile. These, however, are low in response to be suitable for high-speed spectro- , whereas the response time of the indium antimonide s extremely short. The optimum scanning frequency to satisfactory recording on a cathode-ray tube, and to ve simplicity in the design of the cell amplifier, is between d 10 kc/s, and frequencies of this order are easily within cope of indium antimonide.

e construction of the cell is essentially simple, consisting of the photoconductive element enclosed in a flat ctive case, with two flying leads for connexion. The tive area is a narrow rectangular strip measuring × 0·5 mm and the overall dimensions are 12 × 17 × nm.

a wavelength of 6 μ, with a direct current of 50 mA ugh the cell, the ratio of signal voltage to noise voltage is greater than 72 for an ambient temperature of 20° C. The makers give the following additional data.

Minimum detectable power (*noise equivalent power*): Less than 4×10^{-3} μW at 6 μ wavelength and bandwidth of 1 c/s.

Time constant: Less than 1 μs.

Maximum direct current: 100 mA.

Cell resistance: 75 Ω.

Maximum case temperature: 70° C.

Continuous-writing streak camera. Beckman and Whitley Inc., 973 San Carlos Avenue, San Carlos, California.

The continuous-writing streak camera, Model 194, is designed for the study of self-luminous transient events such as explosions, shock-tube manifestations, and flash-tube and spark-discharge phenomena. Because of the continuous-writing feature, the requirement of synchronizing the camera and the event is eliminated, greatly simplifying its use.

The new instrument is mounted on its own base and control housing. Standard 35 mm film, arranged for daylight loading and unloading, is used. The image is swept on to this film by a rotating triangular mirror driven by a high-speed turbine. Several types of this form of drive are available—the fastest one, ranging from 200–5500 rev/s, is driven by helium gas.

This arrangement produces a maximum writing rate of approximately 8 mm/μs, a total writing time at top speed of 58 μs, and a maximum time resolution (using a slit image of width 0·004 in. and film having a resolution of 75 lines/mm) of $4{\cdot}0 \times 10^{-8}$.

The finished useful record is approximately 18·5 in. long. Its length is identified by three fiducial marks automatically placed in the margin of the film which locate the centre of the record and the limit of useful data, which is 114° in either direction.

Model 194 has control equipment which includes an events-per-unit time meter for accurate measurement of the mirror speed to provide a determination of writing rate, mirror-speed adjustments, and controls for the capping shutter and the explosive-actuated blast shutter, used to prevent rewriting in the case of long-duration events.

Manometer. Refinery Equipment and Speciality Co. Ltd., Monton Road, Eccles, Lancs.

A versatile manometer has been developed which is designed for flush-panel wall-mounting, or, with a special stand, for the laboratory bench. The instrument consists of a vertical glass U-tube containing the indicating liquid, with the scale situated between the tubes. The U-tube is held in a solid nickel-plated brass block which contains the valves and fittings, nipples and line connexions for the instrument, and the whole is housed in a cast aluminium case with a transparent plastic front, through which the scale may be read.

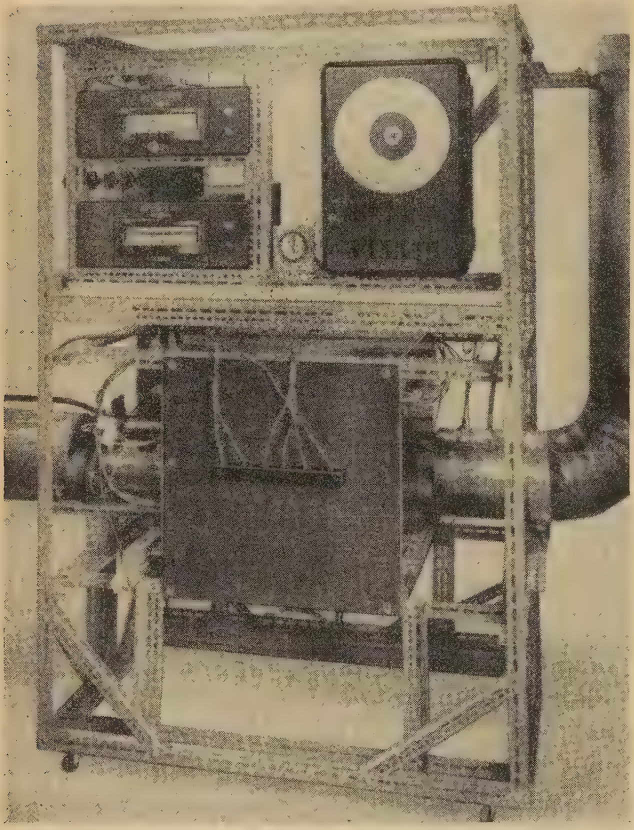
The instrument is intended for the measurement of pressure differences as, for example, occur in the flow of liquids through tubes; it will operate when the mean pressure is 100 lb/in.^{2} Special features are the shock-proof construction, the provision of two line isolating valves and one equalizing valve, and a simple and foolproof system for filling and removing the measuring fluid from the tubes.

Three standard sizes are available with scales of 15, 30 and 60 cm respectively. A free travel of 1 in. on the scale permits an easy zero adjustment.

Atomic energy temperature testing equipment. Foster Instrument Co. Ltd., Letchworth, Herts.

This testing apparatus incorporates the graphite blocks used in reactor construction. Extensive experimental tests were carried out with it which included the measurements (*a*) of temperature gradients in all planes through varying thicknesses of graphite, (*b*) of surface temperatures in the fuel element and isotope channels and (*c*) of the time constants of various types of thermocouples.

These tests were carried out under both static and dynamic conditions; under the latter, air-flow rates of 37 000 to 87 000 ft^3/h were required, necessitating the development of special types of contact thermocouples. The heat source was created by electric blanket heaters on all sides of the block assembly, and by special cartridge and V-formed elements mounted on dummy fuel cans. By controlling the air-flow rates and temperatures, operational conditions representative of any section throughout the entire depth of the reactor can be simulated.

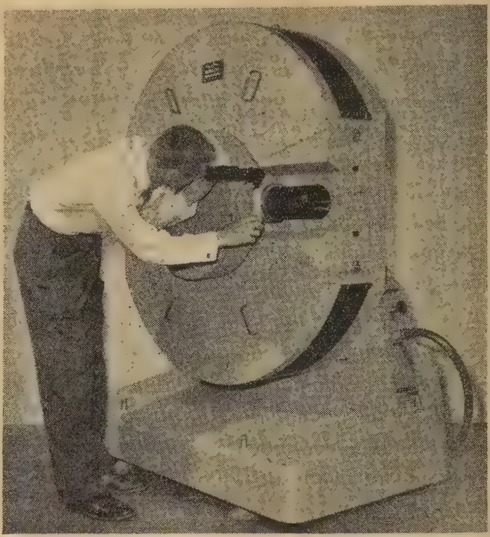


Testing apparatus incorporating the graphite blocks used in the construction of atomic reactors

It is claimed that the above tests and the results obtained should be of vital importance in the instrumentation of reactors.

Continuous-writing framing camera. Beckman and Whitley Inc., San Carlos, California, U.S.A.

The model 192 camera records eighty-two 35 mm frames in a 55 μs period. It is designed to accommodate magnification-velocity products up to 3 mm/μs. The instrument operates with no blind time, which means that it can be used to photograph high-speed events which do not lend thems
to synchronization with the position of the rotating m
in the camera. The camera has boresight optics and
and-pinion focusing arrangements. Daylight loading
unloading are provided by standard 35 mm film casettes



Continuous-writing framing camera

Multi-point recorder for temperature, strain, etc. Savage
Parsons Ltd., Watford, Herts.

This instrument is claimed to provide a permanent pr
record of variable inputs, such as are provided by a d
bution of temperature, strain, d.c. inputs, etc., from any
of 500 points, together with the time at which the mea
ment was taken and the channel identification.

The recorder consists of a main unit, with from one t
extension units coupled to it through a junction box.
main unit contains: the printing mechanism, whic
mechanically coupled to a motor driven slide-wire pote
meter; a high-gain amplifier for the control of the motor
servo-system; a precision voltage supply, based on
standard cell, for comparison with thermocouple or
d.c. inputs; and finally the associated power supplies. T
types of extension units are now available: for strain w
for temperature recording, and for straight-forward
inputs respectively.

The main unit has a printing mechanism which is dr
by a small motor, which also drives the slide-wire poten
meter, so that the figure drums of the printer indicate
position of the moving contact. The method of opera
the system is that the slide-wire potentiometer, which ha
accuracy of 0·01%, provides a d.c. output for compa
with the input e.m.f. This differential e.m.f. is fed into
main amplifier, the input of which is used to control a
of relays for operating the motor. The motor drives
slide-wire to give zero difference signal.

The temperature extension unit contains the term
connexion blocks for the thermocouples, wired (with ther
couple wire) through a fifty-way switch to a "cold juncti
which is in a well-lagged, thermostatically-controlled
kept at a fairly low temperature. The fifty-way switc
automatically advanced one position each time the r

ler reaches the balance, and this also operates the ng mechanism. At the same time the channel identi-n is altered. When the complete number of inputs een recorded, the main unit input is automatically ed on to the next extension unit. The strain extension ontains terminal blocks for active and dummy gauge xions, balancing potentiometers for initial setting-up, lso a bridge power supply. On all these extension there is provision for excluding any one of them from ng during a cycle of operations, without the need for nit to be disconnected.

maximum rate of printing is one hundred points per e, but this can only be achieved if adjacent readings arly the same, so that a minimum of balancing time is ed. The delay in switching from one unit to the next y a few milliseconds. The printing mechanism will between ±999. For strain work this should be alent to ±0·0999% strain. For temperature, the range nded to be from −50 to +999° C using chromel-alumel ocouples.

led scintillation head unit. Nuclear Enterprises (G.B.) td., Bankhead Medway, Sighthill, Edinburgh 11.

hielded scintillation head unit type NE5503, illustrated figure, incorporates a special rotary light-locking device prevents light reaching the photomultiplier during the ing of samples. The sample cell is loaded in a chamber e side of the castle and revolved into the counting on. This operation brings the counting cell in close ct with the photomultiplier. The coupling medium en the photomultiplier and the sample cell is silicone fluid MS200 of low viscosity. The reason for the light-locking device is that a photomultiplier which is not dark-adapted gives a background noise many times greater than it does after being kept in the dark for several days. It is claimed that the rotary light-locking device is superior to an optical shutter system, which requires a finite gap between photomultipler and counting cell with consequent loss of light. A 1 in. diameter photomultiplier of very low noise level is incorporated in the head, along with a White cathode-follower preamplifier of good signal/noise ratio and a 1½ in. thick lead shield.

Scintillation counter with light lock

Electronic computer. Winston Electronics Ltd., Shepperton, Middlesex.

The Beckman–Berkeley EASE analogue computer is at present being manufactured in the U.S.A. and distributed in the U.K. by Winston Electronics Ltd. The computer is assembled to meet individual requirements from a number of basic units. Among such units available are summing, integrating and inverting amplifiers, coefficient potentiometers servo-set by push-button control, electronic multipliers based on the time-division principle, XY plotters, curve followers and chart recorders. The basic computer resistances are adjusted to 1 part in 10^5 and capacitors to 5 parts in 10^5. These components are housed in a thermostatically-controlled oven. The computer is controlled from a central console in which is mounted the patchboard-patchbay system and servo-set potentiometer controls. The patchboard contains 2128 holes and can handle about sixty amplifiers with all associated equipment. The function of an amplifier as a summer-integrator or high-gain amplifier is controlled by patching on the board, not by external switching. This keeps the entire problem on the board and helps to reduce errors of setting when the computer is used by a number of persons. The power to the computer need not be disconnected when removing the patchboard because the amplifiers are automatically returned to inverter operation with a feedback resistor. This ensures that the amplifier output returns to zero when the board is removed. Drift due to thermal transients caused by power switching is therefore eliminated.

The computer incorporates a number of test circuits for checking the correctness of the patchboard wiring. Initial conditions can be checked by applying initial condition voltages to all integrating amplifiers with all summers operative. Summer output voltages can be predicted, thus confirming patchboard connexions and attenuator settings. A second check is made by replacing the output of all summer-integrator amplifiers by a d.c. voltage. This breaks up a complex problem into a series of small simple problems. Integrators are checked by returning them to an initial condition of zero volts and then applying a voltage through a resistor. Any error in time constant of an amplifier is shown by its output voltage differing from that of the other amplifiers.

The computer can be supplemented by a control system using electric typewriters and punched tape. This system will set the coefficient potentiometers from a punched tape, read and print the settings of each coefficient potentiometer, set the computer in operation for a pre-set time interval and then scan and print out the all desired voltages. The computer is then reset and computes for another time interval. The output information can also be punched on tape for use as input information on a subsequent occasion.

Notes and comments

The printing dispute

The delay in the publication of this, and the preceding, issue of the *Journal of Scientific Instruments* has been occasioned by the recent dispute in the printing industry. The editor regrets any inconvenience caused to readers and authors and every effort will be made to return to normal publication dates as soon as possible.

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:—

Fellows: J. C. Bell, S. I. Evans, C. G. Giles, A. E. Hawkins, C. A. Haywood, G. W. Nederbragt, R. L. Russell, C. A. Wass, A. E. Widdowson.

Associates: L. R. Beynon, I. R. Birss, G. S. Bogle, E. F. Bradley, J. C. Castle, C. R. Coleman, C. K. Coogan, J. W. Crawford, J. Dawber, K. M. Derrick, J. H. Dickson, S. N. Dutta, W. T. Eelės, B. Ellingham, K. Goldman, P. H. Herman, E. J. Higham, I. C. Hinckfuss, B. J. Hopkins, N. A. Khan, J. S. Johnston, A. B. Lewis, B. W. Lowthian, M. W. McElhinny, I. J. Macaulay, G. Maidanik, J. Marshall, W. W. Mason, C. S. Metcalfe, J. Morrison, D. F. Cakeshott, J. S. Orr, C. A. Padgham, N. Peacock, D. J. L. Pendleton, J. A. Rausell-Colom, V. M. Rout, J. Scobie, B. Scott, A. J. G. Shaw, J. R. Shepanskie, D. J. Silverleaf, L. Singh, J. Spector, G. M. Sreekantath, P. P. Starling, N. A. Surplice, J. D. Taylor, B. A. Tozer, G. G. Twidle, N. J. Wadsworth, G. White, G. C. Ziman.

Twenty-nine Graduates, fourteen Students and four Subscribers were also elected.

The Journal of Mechanical Engineering Science

We have received the first issue of *The Journal of Mechanical Engineering Science*, a new periodical published by The Institution of Mechanical Engineers in London. This well-produced issue is in the same format as the *Proceedings* of that Institution and is to appear four times a year. The titles of the papers in the issue before us are: Stress concentration factors under dynamic loading conditions; A numerical solution to the elasto-hydrodynamic problem; A refinement in the calculation of the characteristics of shrink-fitted assembly; Instability and steady state coupled motions in vibration isolating suspensions; Determination of the viscosity of steam at super-critical pressures; The effect of hydrostatic pressure on the direct-stress fatigue strength of an alloy steel: The vibration of rotating shafts; The vibration and balancing of an unbalanced flexible rotor; The receptances of uniform and non-uniform rotating shafts.

The subscription rate is £3 p.a. including pos
Further details may be obtained from the Institu
1 Birdcage Walk, Westminster, London, S.W.1.

Powder Metallurgy

In 1957 The Iron and Steel Institute and The Institu
Metals founded a Powder Metallurgy Joint Group h
an official organ called *Powder Metallurgy* which initia
to be published twice yearly, at an annual subscripti
25*s.* including postage.

The first issue is a double one running to 272 octavo p
It contains the inaugural lecture of the group on "R
developments in powder metallurgy" by Ivor Jenkins
papers and discussion presented at the symposium
"Developments in the production and quality of
powders"; the papers and discussion presented at an inf
meeting on "Developments in the practice of compacting
sintering", and the papers presented at the symposium
"The powder metallurgy of metal–ceramic materials".

Correspondence regarding the Group and this new p
cation should be sent to the Secretary of the Gro
17 Belgrave Square, London, S.W.1.

British Journal of Applied Physics

Contents of the August issue

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Spectrum display comparator. By W. J. Price.
Microwave method of investigating the afterglows of pulsed gaseous dis
By M. C. Sexton, J. J. Lennon and M. J. Mulcahy.
Reversible poisoning by sulphur, oxygen and other gases of oxide-coated ca
at high temperatures. By N. A. Surplice.
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Pick-up of copper and duralumin on bonded tungsten carbide. By J.
and G. W. Rowe.
Theoretical evaluation of capillary viscometers for the measurement
viscosity of suspensions of spheres. By A. D. Maude.
Measurement of the quantum efficiency of a proportional counter using
By A. E. Kiss and N. Patla.

Correspondence

Reaction of indium solder with mercury telluride. From S. Nielsen.

NOTES AND NEWS

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the princip
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of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

ORIGINAL CONTRIBUTIONS

Photoelectric double-slit interferometer for investigation of transparent thin solid films

By LEE SANG SOO,* Technical Optics Section, Physics Department, Imperial College, London

[*Paper first received* 23 *March, and in final form* 29 *April*, 1959]

The interferometer is of the Rayleigh two-slit type. A glass plate partly covered by the film to be measured is placed so as to cover one slit and the resulting fringe is a measure of the phase retardation due to the film. The shift is determined photoelectrically using a homodyne detection system to locate the fringe minimum. A sensitivity of $\lambda/7000$ is obtained.

interferometer is basically a Rayleigh refractometer. general arrangement of the apparatus is shown in Fig. 1. t S_3 is illuminated through a monochromator from a n filament lamp S run from a stable supply. Light from collimated by L_2, passes through a double slit S_1 and is ed by L_1 at the plane x, where two-beam fringes are ed. If a slide is placed behind S_1 with a thin film F ing one slit, the fringes are shifted, and they can be ght back to their original position by rotating the

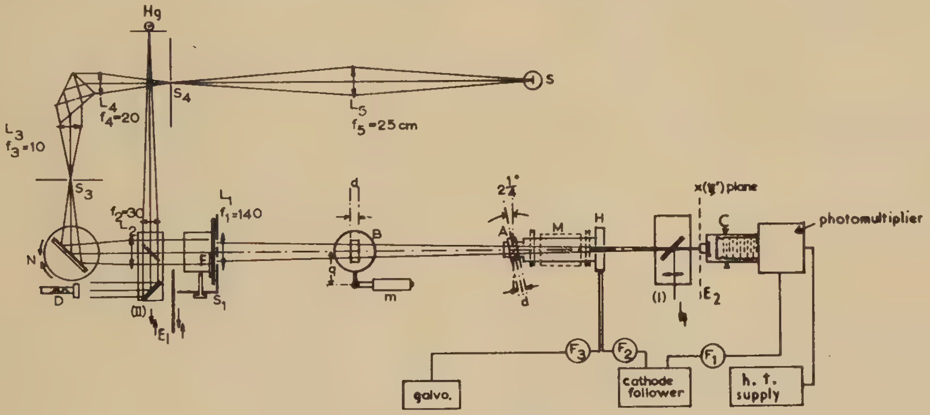


Fig. 1. Schematic diagram of apparatus

A, revolving plate; B, compensating plate; C, cramp; D, direct-vision spectroscope; E_1, E_2, shutters; F, film under test; F_1, F_2, F_3, RC filters; H, half-cycle contactor; Hg, mercury lamp for reference spectrum; L_1, L_2, L_3, L_4, L_5, lens systems; M, d.c. motor (above revolving brass tube; m, micrometer; S, ribbon filament lamp; S_1, S_2, S_3, S_4, slits.

pensating plate B about an axis perpendicular to the e of the diagram.

locate the fringe minima, a slit is placed at x on the cal axis, and a photomultiplier receives the light transed by the slit. A plate A rotates at 600 rev/min about optical axis to which it is inclined at 2¼ deg. This causes fringe system to oscillate across the slit at the above uency. If the mean position of the fringes is such that aximum or minimum is transmitted, the signal will ain no component of the fundamental frequency, but if it will do so. The presence of this signal is detected by modyne (synchronous rectifier) operated from the shaft h holds the plate A.[2,3]

e stationary fringe system B', which is the double-slit nhofer diffraction pattern, can be represented as follows:

$$B' = \tfrac{1}{2}\left(\frac{\sin x}{x}\right)^2\{1 + \gamma_1 \cdot \gamma_2 \cdot \gamma_3 \cos(kx + \Sigma)\} \qquad (1)$$

where $\gamma_1, \gamma_2, \gamma_3$ are the amplitude-difference factor, chromatic-coherence factor and spatial-coherence factor respectively (and their explicit forms will be seen in the next section); x is au' (a and u' being respectively the half-width of a slit in the reduced co-ordinate and the diffraction co-ordinate, $2\pi n' \sin \alpha' \xi'/\lambda$) k is the number of fringes in the central fringe of the single slit diffraction pattern (and is approximately 4) and Σ is the phase difference caused by the film F (Fig. 1) under test.

Because the fringe system is oscillated sinusoidally by the revolution of the plate A, the light received by the photomultiplier $\widetilde{B}'$ is $B'(x + \delta x \, . \sin \omega t)$, and this signal can be analysed as follows[1]:

$$\widetilde{B}' = \widetilde{B}'_{odd} + \widetilde{B}'_{even}$$

so that

$$\widetilde{B}' = (A_1 \sin \omega t + A_3 \sin 3\omega t + \ldots) + $$
$$+ (A_0 + A_2 \cos 2\omega t + A_4 \cos 4\omega t + \ldots) \qquad (2)$$

The d.c. component can be easily eliminated and $\widetilde{B}'_{even}$ degenerates to zero level when the phase-sensitive rectification is applied to the system with respect to the fundamental. Only $\widetilde{B}'_{odd}$ is of interest, and in this the amplitudes $A_{(2j+1)}$ decrease progressively with increasing j. It can be easily shown that if magnitudes less than 0·07% of the value of A_1 are ignored for the amplitude of oscillation of the order of one-tenth of a fringe an approximation for $\widetilde{B}'_{odd}$ can be made with the first two terms:

$$\widetilde{B}'_{odd} = A_1 \sin \omega t + A_3 \sin 3\omega t.$$

Now at Physics Department, College of Liberal Arts and ces, Seoul National University, Republic of Korea.

The terms A_1 and A_3 are given by

$$A_1 = N\left(\frac{\partial}{\partial x} + J\frac{\partial^3}{\partial x^3}\right)B'$$

$$A_3 = N\left(j\frac{\partial^3}{\partial x^3}\right)B'$$

in which

$$J = \frac{(\delta x)^2}{8} + \frac{h^2}{6},\ j = \frac{(\delta x)^2}{24} \text{ and } N = \delta x\,.\,h \quad (3)$$

where h is the half-width of the photomultiplier slit.

The ratio of the two d.c. levels given by the fundamental and the second harmonic after the above mentioned phase-sensitive rectification is $\frac{1}{3}(A_3/A_1)$, and if n resistance-capacitance electric-wave filters are incorporated, the ratio becomes $(\frac{1}{3})^{n+1}(A_3/A_1)$, which is 0·018% if n is 3 and the amplitude of oscillation is one-tenth of a fringe. Thus, the d.c. contribution from the second harmonic may be ignored.

The present interferometric problem is to locate the intensity minimum of the ideal diffraction pattern [B' of the equation (1) with γ_1, γ_2, γ_3 all being unity] by locating the point where A_1 is zero and, as the two points are not identical, a correction term of the order of 0·5% of x can be given. A detailed discussion including computing schemes has been given elsewhere by the author.(1)

CHOICE OF INTERFEROMETER CONSTANTS

Four interferometer constants γ_1, γ_2, γ_3 $(=\Gamma, J, k)$ and N have to be considered, and

$$\gamma_1 = \frac{2\tau_1\,.\,\tau_2}{\tau_1^2 + \tau_2^2},\quad \gamma_2 = \frac{\sin\left(kx\dfrac{\delta\lambda}{\lambda}\right)}{kx\dfrac{\delta\lambda}{\lambda}},\quad \gamma_3 = \frac{\sin(ka\delta u)}{ka\delta u}$$

where τ_1 and τ_2 are the moduli of the amplitudes on the two slits of the double slit and δu is the half-width of the slit S_3 (Fig. 1) in the diffraction co-ordinate.

Constant, Γ. Because the correction term increases sensitively as Γ departs from unity, and also the unbalance of the cathode follower affects the accuracy when it is not unity, it is necessary to design the apparatus with its value as near to unity as possible by making γ_1, γ_2, γ_3 each near to unity. Therefore, when the apparatus is to be used for the investigation of transparent thin films with high refractive indices (for example, zinc sulphide films), the film thickness should be chosen to be $\lambda/2$. For the 100 Å band-width centered about the mercury green line with the aid of the auxiliary optical system (II) in Fig. 1, γ_2 is practically unity even for the largest value of kx which is 180 deg., γ_3, which is the smallest of the three, still has the value of 0·998 when the half-width of S_3 (Fig. 1) is of the order of 10^{-3} cm and the aperture angle of the order of 5×10^{-2} radians, which combine to give the values of $ka\delta u$ as 6·5 deg. for k equal to 4. Thus, to two significant figures, Γ is 1·0 (the correction term is required in two significant figures).

Constants, J and N. The two terms in J of equation (3) are respectively the effect of the finite amplitude of the oscillation and that of the finite width of the photomultiplier slit, and there is no need to make one of these very much smaller than the other. In the present apparatus, the second term is in fact one-sixth of the first term, and the signal is 50 μA, that is, 500 times the dark current at $x = 0$. Because N is directly proportional to the signal level of A_1, if the higher signal level is desired, h can be made larger. Fur the correction term is not sensitive to J and the value m used in the present apparatus is 0·0025.

Parameter, k. This is the number of the fringes in central fringe of the single-slit diffraction pattern, and smaller the value of k, the more rapid is the convergen the terms of the amplitude $A_{(2j+1)}$. However, the smal value means a smaller central opaque portion in the d slit, so that difficulty arises in covering one slit with specimen and keeping the other slit perfectly cleared. double slit with a k value of 4·29 is mostly used ar was produced by aluminizing over glass fibre fixed microscope slide.

The rotating shaft containing the tilted plate is care mounted, because the amplitude of the fringe oscillatio only of the order of 0·2 mm. The plate is fitted to the f of the revolving brass tube, its position being adjust around the axis of the rotation and a half-cycle contact press-fitted to the back end of the tube, so that the phas the fundamental can be adjusted with respect to the p of the contactor. This mechanism is essential because ph sensitive rectification is to be applied to the cathode-follo output from the photomultiplier. The brass tube is dr through two pulleys at 600 rev/min (Fig. 1) from a d.c. m above the tube, and the light source is a 6 V, 18 A rib filament lamp. A photomultiplier, type 6260 (by E.M is used and its output is fed to a balanced cathode follo which leads to the synchronous rectifier and a galvanom (Scalamp galvanometer, by W. G. Pye). A d.c. milliamm provided in the collector lead from the photomultiplier is in setting up to ensure that the maximum light reaches photocathode. The phase of the fundamental current f the cathode follower is adjusted to give maximum signa the galvanometer for a given position of the fringe system

METHOD OF MEASUREMENT

The value of x at which A_1 is zero is determined from micrometer reading m (Fig. 1). The relation between m ξ' the geometrical co-ordinate corresponding to x is as follo

$$\xi' = d\left(\frac{m}{g}\right)^2\left[1 - \left\{1 - \left(\frac{m}{g}\right)^2\right\}^{1/2}\left\{u^2 - \left(\frac{m}{g}\right)^2\right\}^{-1/2}\right]$$

where

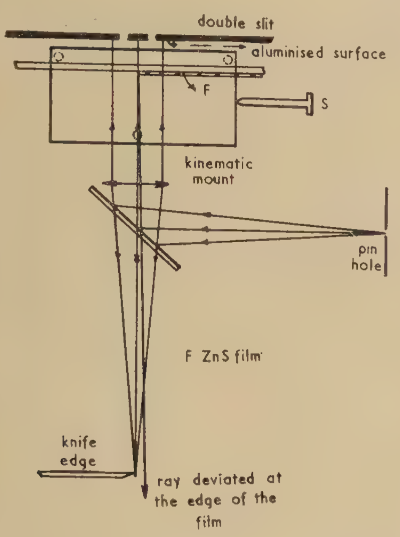
$$\xi' = x\left(a\frac{2\pi}{\lambda}n'\sin\alpha'\right)^{-1};$$

d = thickness of the compensating plate (Fig. 1);
= 1·835 cm;
f = length of the arm of the angular element
= 3·694 cm;
u = refractive index of B
= 1·521 at λ = 5461 Å; and

$$a\frac{2\pi}{\lambda}n'\sin\alpha' = 6{\cdot}165.$$

As the compensating plate is to be tilted up to 11 d the distortion is of the order of 2%, so that the para relation can not be used. The above relation can be ea tabulated so that, whenever m is obtained, the correspond ξ' value can be read in the table. It is then converted t by multiplying by 6·165, and the correction term is fou from the graph provided. Subtraction of this correct term from ξ' gives the true geometrical co-ordinate of sity minimum point, and a simple calculation leads to hase difference caused by the specimen.

setting up the specimen, there are certain experimental ems to be solved. The edge of the specimen must be arallel to the double slit, and brought exactly to the al opaque portion of the double slit. Also, the edge of pecimen must be made very sharp, because the width e central opaque portion is only 15 × 10^{-3} cm. The problem is solved by using an optical system similar to 'oucault knife-edge test shown in Fig. 2. By careful



g. 2. Foucalt knife-edge test for securing parallelism

stment of the knife edge, the light reflected from the inized surface of the double slit is cut off, and the bright 'rom the film edge is observed. When the parallelism is ct, the bright line disappears as the light reflected from lit is cut off, otherwise the bright flare runs upward or nward as the edge crosses the slit.

is method is found to be very sensitive. After the llelism is secured, the mount is replaced in the position in Fig. 1 and the film is gradually screwed in, the deflexion e galvanometer being observed. When the film edge is in the central opaque portion of the double slit, the anometer deflexion is stationary. Finally, the film edge ade very sharp by means of the jig shown in Fig. 3. By means, the edge can also be deposited at a pre-determined ion where the substrate is very homogeneous. This is mined roughly in a Twyman–Green interferometer and more precisely by traversing the uncoated substrate ss the double slit of the present apparatus.

e sensitivity of the apparatus $|\partial G/\partial m|$ is found to be $\frac{1}{3}$, e G is the galvanometer reading in mm units and m is nicrometer reading in 0·01 mm units (the galvanometer has a sensitivity of 187 mm/μA). In other words, when nicrometer is rotated by one division, corresponding to mm translation, the galvanometer deflexion changes by n, the zero point of the galvanometer being observed a magnifying lens. With the above sensitivity, the able deviation obtained in five complete measurements e central fringe width taken over a period of 25 min is 5907, or ±0·053 deg., or 0·015%.

The parallelism between the fringe direction and the photomultiplier slit is secured visually and with the aid of an optical system (I) shown in Fig. 1 and it can be seen easily that it has a second-order effect. The drift of the cathode follower must be watched most carefully during measurements and it is frequently checked by obscuring the light with the shutter s in Fig. 1.

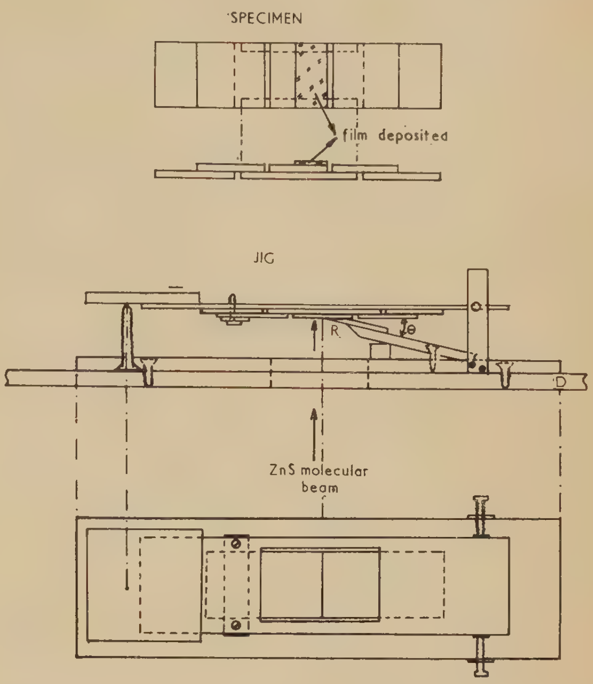


Fig. 3. Jig

D, Dural base plate; *R*, razor blade.

The apparatus has been successfully used in the investigation of the instability of zinc sulphide films prepared by thermal evaporation in vacuum. It is hoped to publish the results shortly.

ACKNOWLEDGEMENTS

The author is grateful to Prof. W. D. Wright for supervising my study here and for the laboratory facilities. Sincere thanks are due to Dr. W. T. Welford for suggesting the problem and for advice and encouragement throughout. Also, thanks are due to the British Council who awarded the scholarship for two years which covered the major part of the period of the present work.

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Sensitive recording magnetic fluxmeter

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The fluxmeter described uses a taut-suspension galvanometer, the torque of which is compensated by positive feedback. This latter is furnished by a servo-operated potentiometer, the wiper of which follows the motion of the galvanometer light spot. The device is an adaptation of a commercially available recorder and permits recording of flux-variations as low as 100 Maxwell-turns per second.

When slowly varying magnetic fields are measured with a fixed coil or the homogeneity of field in an air-gap is determined with an exploring coil moving at constant speed, it often becomes difficult to use a ballistic galvanometer because of its limited time constant. Several electronic devices have been described which allow for longer time constants. The most sensitive ones use photocell amplification of the deviation of a galvanometer and heavy negative feedback through a mutual inductance(1, 2) or a capacitor(3, 4, 5) to accomplish the integration necessary. As the integration time cannot be increased infinitely, the galvanometer coil will, however, tend to drift back to its zero position. Some authors(4, 5) have added positive resistive feedback in circuits of this kind to compensate partially for the restoring torque of the galvanometer suspension. In most photocell amplifiers this, however, becomes dangerous as the linearity of photocells and optical systems used never is perfect and thus will affect the stability and accuracy.

The fluxmeter which is theoretically most satisfying no doubt is the Grassot fluxmeter,(6) which has a pivot or silk-fibre suspended coil and no restoring torque. The sensitivity of this instrument is unfortunately limited. It has occurred to the authors that it is possible to use an ordinary taut-suspended moving-coil galvanometer in the same manner, provided that complete compensation for the restoring torque is accomplished. This can be made only by using a stable and perfectly linear device for detecting the position of the light spot. A carefully designed spot follower recorder equipped with a linear potentiometer may offer such facilities.

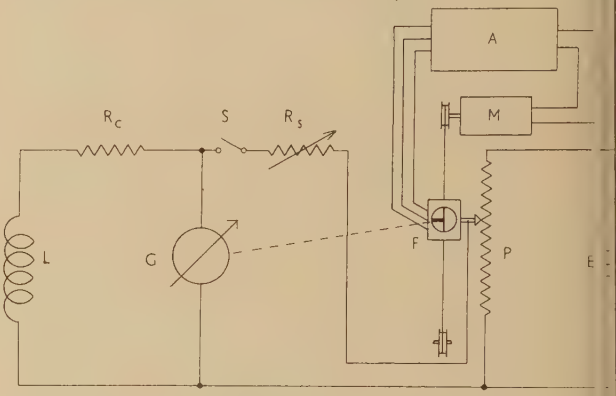
The authors have used a commercially available instrument, the Graphispot recorder model GR4VAD (by SEFRAM Paris). In addition to a servo-mechanical spot-following system this recorder comprises a robust voltage-sensitive galvanometer well suited for the application intended.

The error detector of the spot follower is a small photoconductive cell fixed to the recording carriage. The output current of this cell is amplified by a low-gain symmetrical d.c. amplifier and applied to a servo-motor which corrects for any position error between the light spot and the centre of the cell. When the width of the light spot is not too large, the positioning accuracy (or sensitivity) is better than 0·2 mm. The recording carriage is also equipped with a wiper sliding on a fixed linear potentiometer the output of which then is a direct measure of the position of the light spot. The usual application of this potentiometer is to operate regulating devices, integrators or digital voltmeters. In the present case, it furnishes the voltage necessary to compensate for the torque of the galvanometer suspension.

SET-UP AND ADJUSTMENTS

The potentiometer has a resistance of about 10 000 Ω and a resolution of one part in 5000. The linearity achieved is better than 0·2%. The set-up is illustrated by Fig. 1. The potentiometer is preferably fed from an accumulator stabilized supply. Positive feedback is adjusted by mean a three-decade wire-wound resistance box R_s.

Before making other adjustments, it is necessary to m the zero position of the potentiometer and the mechan zero of the galvanometer coincide very exactly. It is ferable to start with a check of the exact position of potentiometer zero with respect to the pen position on diagram. This can, for instance, be done by the use of ohmmeter or a galvanometer connected between the wi and the zero terminal of the potentiometer. The coincide of the galvanometer zero (switch S open) and the poten meter zero should be adjusted to approximately 0·2 m



Circuit of the torque compensator

L, search coil; R_c, resistance of search-coil circuit; R_s, three decade wire-wound resistance box (10 × 100 kΩ, 10 × 10 k and 10 × 1 kΩ); P, linear high-precision potentiomet (approx. 10 kΩ); F, recording carriage with attached dif ferential photoelectric light-spot detector; A, d.c. amplifie and servo-correcting networks; M, servo-motor; G, light-spo moving-coil galvanometer; E, 4 or 6 V accumulator.

It is possible to verify this zero at any time by opening switch S.

Once the zero is correctly set, the torque adjustment made by diminishing the series resistance R_s down fr 1 MΩ and pushing the recording carriage slightly off its z position until it moves to somewhere in the centre of diagram. Then R_s is increased to obtain a stable posit of the carriage without drift to the right or the left. control of the correct current injection should be made other positions of the carriage (for instance, at one-fou and full-scale deviation) by bringing the carriage to th positions by hand. When no drift occurs for any posit of the pen, the mechanism is ready to operate as a fluxme

SENSITIVITY

The requirement on the galvanometer itself is no longe very high-current sensitivity nor a long period, both imply a quite delicate suspension. Zero displacement y kind, mechanical or electrical, will cause a slow drift recording carriage, and a rather stiff suspension is thus rable because this usually means less zero drift and resis.

ere is a threshold value of e.m.f. below which integra-will not take place. This threshold is determined, on and, by the photoelectrical-mechanical backlash of the ding carriage and, on the other hand, by the voltage tivity of the galvanometer circuit. Above this e.m.f. integration will be correct independently of the time ion of the phenomenon recorded.

e galvanometer incorporated in the GR4VAD recorder the Schlumberger–Picard(7) liquid-immersed vibration-sitive type. Its coil resistance is 20 Ω and its time of ation normally 1·8 s when used on a circuit of 300 Ω. ositive feedback increases period and critical damping ance, it should be possible to use even higher search-resistances. It is, however, preferable for correct eter operation (heavy damping) but also for sensitivity ns to keep the circuit resistance low, for example, w 500 Ω. The current sensitivity of the galvanometer is A for full-scale deflexion (250 mm). Assuming the lash of the servo-mechanism to be 0·2 mm, this corre-ds to 0·06 μV on a circuit of 10 Ω and to 1 μV on a circuit. Apart from these threshold values which ractice are very low, the set-up will have the same erties as those predicted theoretically for fluxmeters and ed in the literature. The fact that the Schlumberger–rd galvanometer has substantial viscous damping intro-d by its perchlorethylene filling will have almost no r influence than to decrease somewhat the flux sensitivity to make this dependable on the external circuit resistance.

ith a search coil of 100 Ω resistance, the sensitivity ned was 10 Maxwell-turns/mm or 2500 Maxwell-turns, scale. The corresponding sensitivity limit is, in this case, μV or 25 Maxwell-turns/s.

the search-coil resistance is higher than 500 Ω, a gal-meter having a higher critical damping resistance should sed. The more current-sensitive galvanometer of the rder, model GR2VAD, made by the same manufacturer, seems to be better suited but the flux-linkage sensitivity be reduced about five times.

FREQUENCY RESPONSE

e low-frequency limit above which correct integration d be expected corresponds practically to a flux change 00 Maxwell-turns/s with a circuit resistance of 100 Ω. e high-frequency limit is set by the response of the spot-wing servo-mechanism, which fortunately is remarkably d. The maximum following speed is approximately mm/s and one can consider that this corresponds to a change of 6000 Maxwell-turns/s with the same circuit tance as before. By limitation of the amplitude of the variation to a few centimetres on the diagram, it is ible to follow in practice any high-speed transient with-losing the light spot. In many measurements, however, flux variation can often be slowed down artificially to w the normal high-frequency limit of the mechanism.

STABILITY

e zero setting of the galvanometer is, as mentioned re, quite critical. The photoelectric detector and the amplifier do not present any measurable zero drift and the drift of the galvanometer suspension is negligible if sufficient warm-up time is allowed for before making any adjustments.

As in all fluxmeters, any e.m.f. which exceeds the sensitivity limit and is set up in the circuit after the original zero adjustments will cause steady drift. Stray thermoelectric forces may therefore be troublesome and are often unavoidable. It is, in any case, necessary to protect the measuring circuit of the galvanometer against thermal variations. All connexions should be made with copper wire and screwed joints should be free from nickel plating and should be thermally insulated. From the experience of the authors, it seems preferable not to use a lower circuit resistance than 100 Ω if noticeable drift was to be avoided. Shunts should therefore be used with care because of the risk for increased sensitivity to thermoelectric forces. With a coil resistance of 100 Ω or more it was found that the apparatus could be adjusted to show no drift for periods up to ten minutes—a sufficiently long time for exploring an air gap with high resolution. In any case, recorded variations of the order of 25 Maxwell-turns/s or less should be disregarded as they are below the normal sensitivity limit.

LONG TIME-INTERVAL RECORDING

In the necessity for recording over a long time interval of periodic variations as, for instance, rapid fluctuations of the earth's magnetic field, it is possible to overcome troublesome drift either by automatic zero setting with the aid of the switch *S* or by diminishing somewhat the positive feedback, thus leaving some restoring torque to the galvanometer. As both negative and positive variations are to be measured, the mechanical zero of the galvanometer should then be brought to the middle of the diagram, and the potentiometer circuit modified so as to give zero output for this position of the light spot by using a centre-tapped voltage divider on the accumulator.

CONCLUSIONS

The fluxmeter set-up presented has the advantage of using a commercial laboratory recorder and very few extra parts. This recorder can without modifications and at any time be reconverted for its conventional use. Furthermore the flux sensitivity supersedes most long-period galvanometers, and directly visible records are obtained. The galvanometer incorporated in the recorder is insensitive to vibrations, and the apparatus thus does not need any special support. An *XY* version of the recorder would permit the direct tracing of hysteresis loops.

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Use of electric-current shims in the cyclotron

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The design and the method of construction of electric-current shims for the Birmingham cyclotron are described. Measurements are given showing the effects of these on magnetic-field distribution. Representative beam-current measurements are given which show that with shim-currents up to 500 A, the method was successful in making possible the acceleration of H^+ or $^3He^{++}$ ions with about the same efficiency as the D^+ ions for which the permanent steel shims were adjusted.

It is well known that, in order to use a particular cyclotron magnet to the greatest advantage, the pole tips must be shaped carefully to give a suitable rate of fall-off of magnetic field with increase of radius. Plain, flat pole tips give too little field gradient near the centre to provide adequate vertical focusing of the beam, and begin to give an excessive gradient well within the outer radius, so preventing the maximum possible energy from being obtained. The pole tips, which usually form the top and bottom of the vacuum box, are therefore shaped to give the best possible distribution of field for the particular magnet-current which it is intended to use. Provision is usually made for introducing steel shims between the pole pieces and the main magnet in order to compensate for non-uniformities and inaccuracies in the pole pieces themselves and to give some control of the precession of the beam. This is important when efforts are being made to extract the beam. The inner profile of one of the steel poles used at Birmingham is shown in Fig. 1. This is designed to suit the acceleration of deuterons at 13 500 G. Of particular importance is the ring-shim which is needed to prevent excessive fall-off of field at the outer radii.

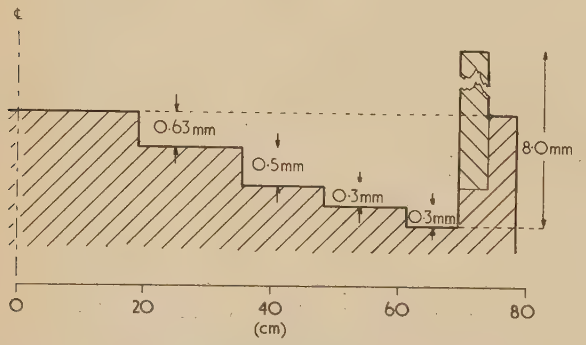

Fig. 1. Inner profile of the steel lid of the cyclotron vacuum tank, which forms the magnet pole tip

The magnet gap is 25·4 cm at the centre.

PROBLEM

The solution given above is quite satisfactory for acceleration of a single kind of particle. If, however, it is also required to accelerate particles with different values of e/m, it is less satisfactory. In most fixed-frequency machines, and certainly in the Birmingham cyclotron, it is very troublesome to change the operating radio frequency, and hence it is necessary to change the magnetic field. Because of saturation, the effect of the ring-shim on the shape of the field is greater at lower fields and less at higher fields than it is at the deuteron field. To measure the magnitude of this effect, a simple and stable proton-resonance magnetometer designed.

The proton-resonance equipment used a water sam contained in a tube (about 0·3 mm diameter and 20 long) set at right-angles to the radius and parallel to median plane of the magnet. The width of the resona line of the water was broadened to about 0·1 G by addition of ferric chloride and the resonance frequency measured with a wave meter, type B.C. 221 (by Raulan Co Chicago), which gives an accuracy of 1 part in 10^4 or bet The resolution of the equipment in a uniform field of ab 10 000 G was 0·05 G. The gear would work with redu resolution in non-uniform fields with gradients up to 15 G/ across the diameter of the sample. The resonance head made to fit inside a standard re-entrant target tube so t measurements could be made with the tank evacuated. (gradient of the magnetic field changed appreciably evacuation of the tank because of the elastic distortion the 10 cm thick steel cover plates.)

The distribution of magnetic field in the median plane explored at a series of values of the mean field. The res are shown in Fig. 2 for four cases of practical interest w mean fields appropriate to the acceleration of $^{14}N^{6+}$, D $^3He^{++}$ and H^+. It is easily seen that acceleration of ^{14}N to full energy would be difficult without a very high

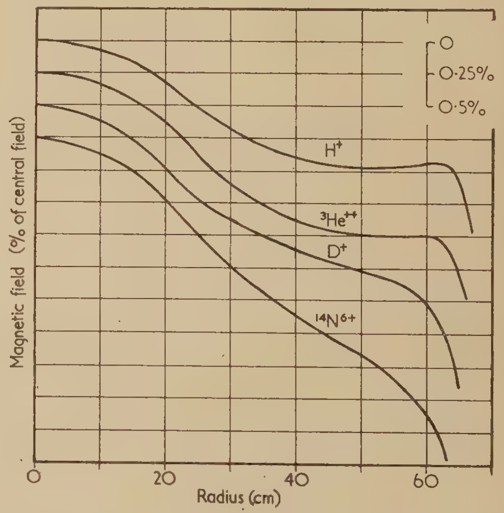

Fig. 2. Variation of magnetic field with radius, plotte in each case as a percentage of the central field appropriate for the acceleration of the indicated particle

The values of these fields were as follows: H^+, 6750 G; $^3He^{++}$, 10 100 G; D^+, 13 500 G; $^{14}N^{6+}$, 15 700 G. The curves are arbitrarily displaced vertically to avoid overlapping.

age to overcome the rapid drift of phase, while beams of $^{++}$ and of H$^+$ would mainly be lost by defocusing near and 49 cm radii respectively. This was in accord with ervation. Good low-energy beams of ^{3}He^{++} and of H$^+$ e obtained, but fell to vanishingly small values near the i expected. Full-energy ^{14}N^{6+} beams could be obtained, only at high r.f. voltages. The beam currents were ays small, though this would be true anyway because of complex mechanism of acceleration.

PRINCIPLE OF ELECTRIC-CURRENT SHIMS

n order to avoid the loss of beam, it is necessary to change slope of the magnetic-field H/radius r curves by only a ll amount, and only over a short radial range. To do this iently one must make the necessary modifications *inside* steel pole tips, because the latter will smooth out any al variations in field produced outside them—this being, fact, one of their intended functions. Now the desired ct could clearly be given by similar parallel loops, carrying quate currents, at the top and bottom of the chamber. he currents in the loops are in the same sense as those in windings of the main magnet, they will raise the magnetic d inside the loops and lower it outside. They will thus e a negative value of dH/dr in the region of the loops. ernal coils have been used in other machines to eliminate gularities of field and to assist in the setting-up of a ong-focusing field, but the information available was not ough to see whether or not this negative dH/dr could be de large enough for practical use in the Birmingham chine. Some preliminary measurements were therefore de with the proton-resonance equipment already men-ned, using short arcs of current-carrying conductors inside tank with the dees removed. It was found that, with A in each conductor, a negative value of dH/dr could obtained which was appreciably larger than the largest sitive value shown in Fig. 2.

After one or two attempts to use screened shims on top the existing water-cooled copper face plates covering the le pieces, new copper face plates were obtained, and annels were turned in these. Earthed copper screens elded the leads to their points of exit from the tank. ur loops were installed on each face plate, at radii of 41, , 61 and 67·5 cm. The variation of field with radius, in nditions suitable for acceleration of H$^+$ ions, was measured st with no shim-current and then with 400 A in each pair loops in turn, omitting the 67·5 cm pair which proved to too far out to be as useful as the rest. The absolute change field introduced by each pair of loops is shown in Fig. 3. will be noticed that the effect of the 61 cm loops is almost e same as that of the 51 cm loops, probably because of the close approach of the former to the partially-saturated edges of the pole tips. The bump in the field was completely eliminated by either of the two intermediate shims, as is shown by the curves of Fig. 4, plotted in the same way as in Fig. 2. The effect of the shims on the ^{3}He^{++} field was very similar. The result of using the shims with actual beams of H$^+$ and of ^{3}He^{++} was quite as good as was hoped: in each case, not only could the particles be brought to the maximum radius, but useful external beams could be obtained.

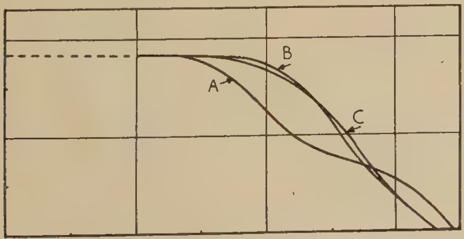

Fig. 3. Change in magnetic field on the median plane, produced by 400 A in each pair of loops in turn. (Central field, 6750 G)

Curve *A*, 41 cm loops; curve *B*, 51 cm loops; curve *C*, 61 cm loops.

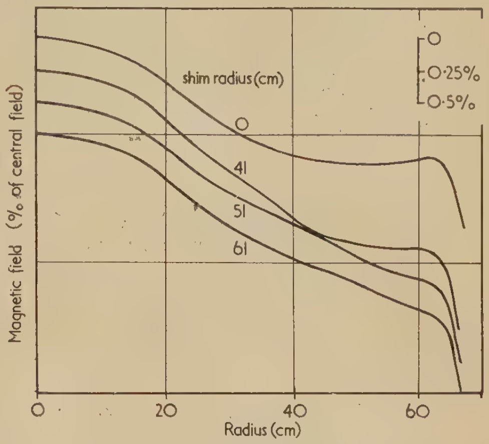

Fig. 4. Variation of magnetic field with radius, plotted as a percentage of the central field, with 400 A flowing in each pair of shim loops, as indicated on the figure

The mean field is that required for acceleration of H$^+$ ions, 6700 G.

At first, the insulation consisted of p.t.f.e. tape wrapped round the conductor. After a few weeks of operation, however, this broke down, probably because of to-and-fro movements of the loops resulting from expansion and from magnetic forces. In the final arrangement, therefore, each loop has been wound with four layers of fibre-glass tape, painted with casting resin, type "F" (by Araldite) before and during the winding of the tape. Each was then set in its individual channel with more casting resin, and the temperature of the whole assembly raised to 100° C for curing. A cross-section of the conductor lying in its channel is shown in Fig. 5.

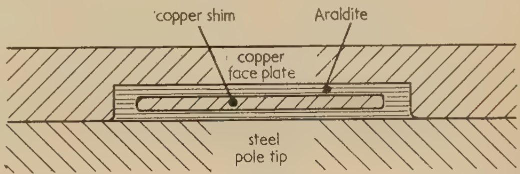

Fig. 5. Cross-section of one of the final current-shims

At this stage only the two intermediate loops, having radii of 51 cm and 61 cm were retained, as the introduction of four sets of leads was very troublesome and the optimum performance had proved to be obtainable without the use of the 41 cm and 67·5 cm loops. A final improvement was to provide water cooling for the 12 mm copper rods which, passing through O-ring seals, carried the shim-current through the wall of the tank.

Since this system was installed, several months of trouble-free operation have been experienced with currents of up to 500 A and the system could probably be operated at 750 A if it were useful to do so. Less current would, of course, be needed if each loop were built up of several turns but it was thought more convenient to handle, and easier to insulate, a single low-voltage conductor. Each pair of loops was supplied from a separate 6 V plating generator, making it independently variable.

PERFORMANCE

In Fig. 6 are shown currents of H^+ at several radii, as a function of shim-current. Qualitatively, similar results were obtained with $^3He^{++}$ beams. Very little work was done to find the optimum conditions and, in particular, the steel shims used in the shimming gap for deuterons and α-particles were left untouched. These could hardly have been in the best position for the mean fields for both H^+ and D^+ and th fore the currents were probably not the best obtaina For practical purposes, however, it was essential to leave steel shims untouched, as the whole point of the system to make the change from one particle to another as eas possible. This is especially important with $^3He^{++}$. this, it is the usual practice to adjust the machine at leis with ordinary helium fed into the arc, for a maximum b of α-particles. When this is obtained, it is only necess to adjust the main magnetic field together with the deflec if an external beam is used, switch on the shim-cur generators and switch the source over to the circula system for $^3He^{++}$. A maximum beam of $^3He^{++}$ ions then be obtained in two or three minutes, with a mini loss of ^3He.

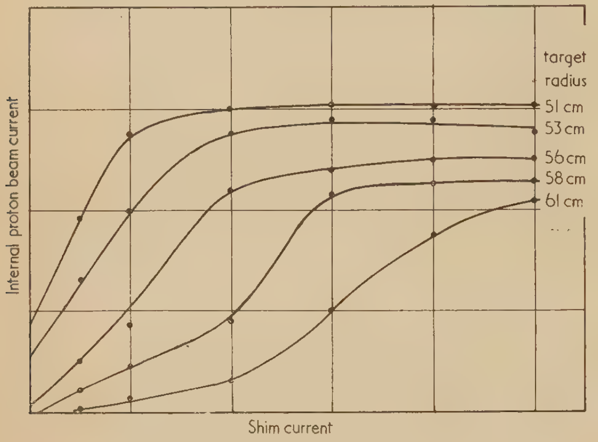

Fig. 6. Variation of internal proton beam current with shim-current for various target radii

The mean magnetic field was adjusted for each reading and other conditions were kept constant. In all cases, the current which is indicated was flowing simultaneously in both 51 cm and 61 cm shims, all four loops being connected in series.

CONCLUSION

The use of current-shims is thus effective in makin possible to accelerate particles with values of e/m la than that of the deuterons for which the cyclotron designed. The effect on beams of $^{14}N^{6+}$, for which $e/$ smaller than for the deuteron, is less useful. For this sh currents in the opposite direction were used to reduce rapid fall-off of the field, but little heavy-ion work has b performed since the final installation and an adequate may not have been carried out.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the members of the cyclotron team, Mr. T. Cartwright, M Lilley and Mr. F. Stewart for many useful suggestions a great deal of help with the practical work.

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Use of scintillation counters in single crystal X-ray diffractometr

By P. J. Black* and J. B. Forsyth, Crystallographic Laboratory, Cavendish Laboratory, Cambridge

[*Paper received* 20 *May*, 1959]

The paper describes a scintillation counter apparatus used for single-crystal X-ray diffractometry. The variation of the signal/noise ratio with photomultiplier operating potential has been investigated for the Du Mont 6291 tube, and it is shown that the resolution of the signal pulses from the noise background improves as this potential is decreased. Signal resolutions of 26, 29 and 43% have been obtained with AgKα, MoKα and CuKα radiations respectively, the mean number of photoelectrons released per keV incident quantum energy being 6. Stability criteria which will help to ensure the overall uniformity in the counter response are suggested.

1. INTRODUCTION

Several workers (West, Meyerhof and Hofstader,(1) Brentano and Ladany,(2) Nelson and Ellickson,(3) Parrish and Kohler(4)) have investigated the possibility of using scintillation counters for accurate measurement of X-ray intensities in crystallographic studies. In particular, Parrish and Kohler(4) have made a detailed comparison of the properties of Geiger, proportional and scintillation counters in order to guide the choice of the most suitable counter in any specific problem.

We have chosen to use a scintillation counter for the accurate measurement of intensities from small single crystals at wavelengths between AgKα (0·56 Å) and CuKα (1·54 because the absorption of the AgKα radiation is so small proportional counters. In setting up and testing the coun we have found that the optimum conditions for this type application are not fully specified in previous publicati This paper presents results which should be taken i consideration by those using this type of counter for si crystal diffractometry.

2. EXPERIMENTAL

Small blocks (0·6 × 0·6 × 0·1 cm) of NaI.(Tl) scin lator were cleaved from single crystals; optically clear blo with good cleavage were selected for mounting. The thi of 0·1 cm is sufficient to absorb 99·8% of AgKα ation. Each crystal was placed in optical contact with ıss disk using a layer of dry paraffin oil, and covered with luminium cap. This cap was made by pressing a piece ·01 in. foil on a former to the shape shown (Fig. 1). vindow *W* was cut from the foil and covered with 007 in. aluminium. The interior of the cap was electroly- ly polished, and the cap was sealed to the glass with cold ng Araldite.

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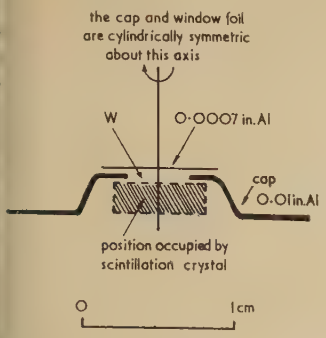


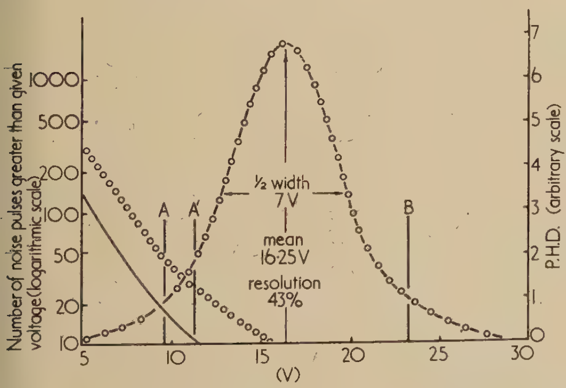
Fig. 1. Schematic diagram of the scintillation crystal mounting

his assembly was then attached with paraffin oil to the of a Du Mont 6291 photomultiplier tube (p.m.t.), and tube was mounted in a mild steel case which was light-tight provided some magnetic shielding. X-rays could enter case through a 0·005 in. beryllium window.

n I.D.L. type 532/A stabilized power unit supplied voltage he p.m.t. The counting chain consisted of a linear, high (50 000) pulse amplifier (A.E.R.E. type 1043), a single ınel pulse height analyser, and a Scarrott(5) scaler. The ır surface of the p.m.t. was coated with Aquadag and this ducting shield was connected to the photocathode (see ay and Varga(6)).

3. MEASUREMENTS

ulse height distributions (p.h.ds.) for the pulses produced CuKα monochromatic radiation are shown in Fig. 2. set of results was obtained with 1200 V applied to the e, the other with 800 V applied. The fall in photo- tiplier gain in the latter case has been compensated by increase in amplifier gain, so that the signal p.h.ds. coincide. The background noise distributions for the two h.t. voltages are appreciably different and are shown in the figure as integral curves (that is, as a graph of the number of pulses greater than a given voltage) plotted on a logarithmic scale. The mean background in a discriminator channel set to receive 90% of the signal pulses is 60 c/m (counts per minute) for 1200 V h.t. and 20 c/m for 800 V h.t. There was continuous improvement in signal to noise ratio with decreasing tube potential down to 800 V, at which potential the maximum amplifier gain was being used. The background p.h.d. was not significantly altered by removing the scintillation crystal, so that this noise must originate in the tube. This effect was investigated by Engstrom(7) who concluded that it could not be associated with thermionic emission from the photocathode, but might be due to field emission. This implies that the effect is dependent on the interstage potential, and mainly on the first stage potential. This potential was normally set at 150 V, higher than the mean interstage potential, to ensure complete collection of the photoelectrons. When the first stage potential was increased, the shape of the CuKα p.h.d. was unchanged, which showed that the collection efficiency had not been improved. However, the noise in the CuKα channel increased to 30 c/m for an increase of 40% in the first stage potential, which is consistent with Engstrom's suggestion. When the potential was lowered, the CuKα p.h.d. became broader, showing that the collection efficiency had been impaired. There is thus an optimum voltage for the first stage, below which the signal to noise ratio decreases because the discriminator channel has to be wider to collect 90% of the broader distribution, and above which the ratio decreases because the noise effect is increased, whilst the collection efficiency is already a maximum.



ig. 2. CuKα p.h.d. (right-hand scale) and the integral ark noise curve (c/m) for two different p.m.t. operating voltages:

———— 800 V h.t., amplifier gain 50 000

○ ○ ○ ○ 1200 V h.t., amplifier gain 2920

he p.h.d. is a differential curve and shows the number f pulses received in unit time per unit voltage range

Brentano and Ladany(2) found that they could not easily discriminate CuKα pulses from the noise interference, and their difficulty is explained by the low photocathode response (18 electrons per quantum of MoKα, i.e. 0·97 electrons per keV). Nelson and Ellickson(3) worked with better sensitivity (3·5 electrons per keV) and give the impression that their counter was satisfactory for use with Cu radiation. However, they quote no background figures and only show p.h.ds for such high counting rates (of the order of 10^5 c/m) that any background effects are masked. None of these authors mentions the operating conditions of the photomultiplier. Parrish and Kohler(4) state that the choices of counter tube voltage and amplifier gain are not critical and use p.m. voltages between 800 and 1100 V. They quote a non-X-ray background of 9·0 c/m for a discriminator channel set to receive 90% of CuKα pulses, but do not specify the tube voltage at which this figure was obtained. Their results show a count of 31 per minute for background pulses on the high energy side of the CuKα channel: our corresponding figure is 5 c/m, whilst our crystal volume is only 15% smaller. They seem to find a background dependent on scintillation crystal volume which is much greater than ours, but with discrimination obtain a lower background. The difference between their 9 c/m and our 20 c/m may be explained as variation between individual p.m. tubes, though they do not say that theirs was specially selected for this particular measurement. We have used three tubes and find that the noise p.h.d. for a given tube voltage, and the resolution of signal pulses are similar, but that the tubes differ in the mean signal amplitude produced at a given voltage. Thus a tube with a higher gain could be run at a lower voltage and so contribute fewer noise pulses to the CuKα channel. However, in all cases this background could be improved by lowering the tube voltage. Fig. 3 shows the variation in the distribution of dark noise pulses with h.t. voltage for one of the p.m.ts. The amplification has been adjusted to produce the same mean pulse height for one characteristic wavelength (in this case AgKα) and this is marked on the figure, together with the mean pulse heights for CuKα and MoKα.

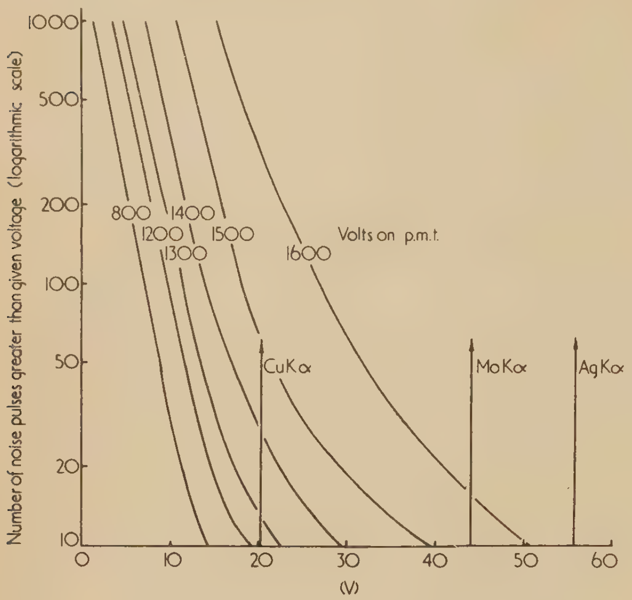


Fig. 3. Integral dark noise curves for various p.m.t. operating voltages. (Scale in counts per minute)

The p.h.ds. for MoKα and AgKα radiations have resolutions of 29 and 26% respectively. The improved resolutions and the larger mean pulse heights result in the pulses being more clearly separated from the dark noise, and the tube voltage is no longer so critical. The backgrounds in a channel set to accept 95% of the pulses are 3 c/m for MoKα and 2 c/m for AgKα, with a tube voltage of 1100 V and an amplifier gain of 5600. This gain is available in most types of pulse amplifier, without the use of a head amplifier. With the p.m.t. operating at the maximum safe potential of 1600 V a gain of only 450 was needed to measure the AgKα p.h.d. whilst the background increased to 33 c/m.

4. DISCUSSION

The 6291 p.m.t. is a 10-stage tube, and it would appear that with the extra gain available in an 11-stage tube (e.g. the E.M.I. types 9502B or 9524B) or a 14-stage tube such as the R.C.A. 6810A it should be possible to use an external gain of about 500 to detect CuKα and harder radiations whilst counting very few dark noise pulses, as high p.m.t. h.t. voltages would not be required. It is not possible to estimate the noise contributions for these p.m.ts., as the manufacturers' specification does not include the p.h.d. of the tube noise.

The mean number of photoelectrons per keV incident quantum energy, calculated from the resolution of the CuKα pulses, using an approximation due to G. T. Wright,(8) is 6, which compares favourably with the highest sensitivity previously quoted (5 by Parrish and Kohler). This performance depends on efficient collection of the light produced in the scintillator. For example, when the aluminium window was replaced by one of beryllium whose inside surface had not been treated by coating with aluminium to increase its reflectivity, the reduction in resolution and pulse height showed that the number of photoelectrons produced
quantum was reduced by 30%.

Our measurements on discrimination against λ/2 and
X-ray backgrounds agree with and do not extend thos
Parrish and Kohler.(4)

We have attempted to check the stability of the cou
response with variations of several experimental conditi
The conditions for stability in the electronic circuits sh
be determined from the setting of the discriminator le
The p.h.d. at these settings will determine the drift in m
pulse heights which can be tolerated for a given coun
accuracy. These drift conditions will then determine
stability criteria for the tube voltage, amplifier gain,
discriminator levels. For example, an attempt to reduce
dark noise background for CuKα by moving the discrimin
level A to A' (Fig. 2) would reduce the drifts which coul
tolerated for a given counting accuracy. As an indica
of the stability required, the discriminator levels A an
(Fig. 2) have to be stable to better than $\pm 0{\cdot}25$ V to ach
an error of less than 1% in the total counts received.
change in overall gain of 7·5% would cause a 1% decr
in the number of pulses, and as most laboratory ampli
are stable to ±1%, this change in gain can be regarde
the criterion governing the stability of the h.t. supply to
p.m.t. A 10- or 11-stage tube has a gain which va
approximately as V^8, where V is the applied voltage, an
1000 V 7·5% change in gain results from a 9 V h.t. d
Whilst 0·9% stability is easily maintained by most po
supplies which are similar to the type used, the h.t. vol
must be capable of being reset to the required accuracy if
unit is to be switched off in its day-to-day operation.

We have checked that the response of the counter did
vary as the incident X-ray beam moved through s
distances relative to the scintillation crystal. Non-uniform
in response may be caused by imperfections in the scintilla
crystal, bad focusing geometry or rapid variations of
photocathode sensitivity across the illuminated area. A be
0·5 mm square was aligned to fall centrally on the thin
window (Fig. 1) and it was found that the centre of
beam could be misaligned by 0·9 mm without altering
counter response. This meant that the alignment a
mechanical stability of our apparatus were not critical.

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We are grateful to Prof. N. F. Mott and Dr. W. H. Tay
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Method of amplitude control of a.c. signals

By J. B. Cornwall, Grad.I.E.E., Auckland Industrial Development Laboratories, Dept. Scientific and Industrial Research, Auckland, New Zealand

[*Paper first received* 4 *December*, 1958, *and in final form* 1 *April*, 1959]

A circuit for controlling the r.m.s. value of an a.c. signal is analysed and practical results are discussed. The speed of response is such that for rates of change of 2·5% per second the output is controlled continuously within 1%. An alternative arrangement for maintaining, at a preset level, the peak value of repetitive pulses is also given.

; frequently necessary to stabilize either the r.m.s. or (value of a small a.c. voltage, an example being the ge input voltage in a carrier-amplifier system. The hod described uses a thermistor as a controlled element resistive attenuator. A simplified circuit diagram of an s. controller is shown in Fig. 1. The voltage to be trolled, E_{in}, is applied to the attenuator formed by the stor R_1 and the thermistor R_t. The fraction of E_{in} earing at the grid of V is amplified, producing a signal after suitable transformation. E_{out} is applied to the ter winding of the thermistor thus controlling the resis- ce of R_t. When the value of E_{in} increases, E_{out} tends to ease, supplying more power to the thermistor heater, s reducing the resistance R_t and, consequently, the tion of E_{in} applied to the grid of V. In this manner, the plitude of E_{out} is kept substantially constant.

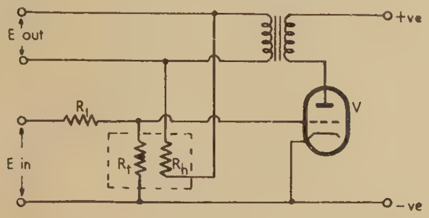

Fig. 1. Circuit of r.m.s. controller

he relation between E_{out} and E_{in} can be derived as follows:

$$E_{out} = E_{in} \times \frac{R_t}{R_1 + R_t} \times M, \qquad (1)$$

ere M is the voltage gain of the amplifying stage. The perature T of the thermistor can be related to the power ipated (W) in the heater winding R_h over a small range temperatures, by:

$$W = C(T - T_0)$$

ere C is a constant expressed in watts per degrees Kelvin, l T_0 is the ambient temperature expressed in degrees lvin. Because:

$$W = \frac{(E_{out})^2}{R_h}, \quad \text{and} \quad R_t = Ae^{B/T}$$

ere A and B are constants for a given temperature and e he base of the naperian logarithm tables, then:

$$\log_e R_t = \log_e A + \frac{BC}{(E_{out})^2/R_h + CT_0}. \qquad (2)$$

equation (1) is solved for R_t and the value substituted in uation (2), then:

$$\log_e\left(\frac{E_{out}R_1}{ME_{in} - E_{out}}\right) = \log_e A + \frac{BC}{(E_{out})^2/R_h + CT}. \qquad (3)$$

This expression contains the variable E_{in} and the dependant E_{out}, all other symbols being constants.

The constants of such a circuit were determined experimentally using a thermistor, type B8320 (15P/330k) (by Philips), and a graph of E_{out}/E_{in} was constructed from equation (3). This is Curve *A* in Fig. 2. Curve *B* shows the actual curve obtained in practice. Below the controlling level the theoretical curve is in error by about 6% but throughout the controlled range is within 3% of the actual value.

An improvement over Curve *B* is shown in Curve *C*, where an N.T.C. resistor, type B8320 (O3P/2K2) (by Philips) has been placed in series with the heater winding. Because the resistance of this component decreases with increasing voltage, the effect is to increase the portion of E_{out} which appears across the heater winding as the output voltage rises.

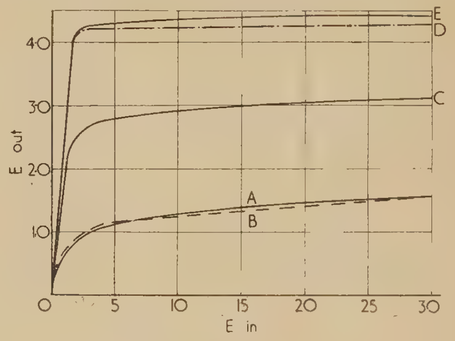

Fig. 2. Relation between input and output voltage

In an attempt to raise the level of controlled voltage, higher values of series N.T.C. resistors were tried, and Curves *D* and *E* are given for values of 5 kΩ and 100 kΩ respectively. These results indicate that the optimum value of series resistor is approximately 5 kΩ, resulting in a controlled voltage of 4·2 V. The output transformer should therefore have one secondary to match 250 Ω at 4·2 V, and others to provide the required output voltages.

Because of the thermal delay of the thermistors, the time for the output voltage to reach a given percentage of the final value, after a change in input voltage, depends on the rate of change and the limits through which the change occurs. For rates of change not greater than 2·5% per second, the unit will control continuously within 1%. For sudden changes the following figures are given using an operating point at about the centre of the flat portion of the characteristic:

Reduction of 50% controlled within 1% after 4 seconds;
Increase of 100% controlled within 1% after 3 seconds.

Fig. 3 illustrates the stabilizing effect of the r.m.s. controller on the output of an oscillator which has been deliberately made unstable for the demonstrations, the rate of paper feed being 1 division per hour. The effects of ambient temperature changes have been investigated. From 50–70° F no significant change in controlled voltage occurred, but above this the output decreased at the rate of about 1% per 5° F. A long term stability run showed a reduction of output, initially at the rate of 3% per week, but dropping after 4 weeks to 1% per week. A modification to the circuit so that peak rather than r.m.s. voltages are controlled is shown in Fig. 4.

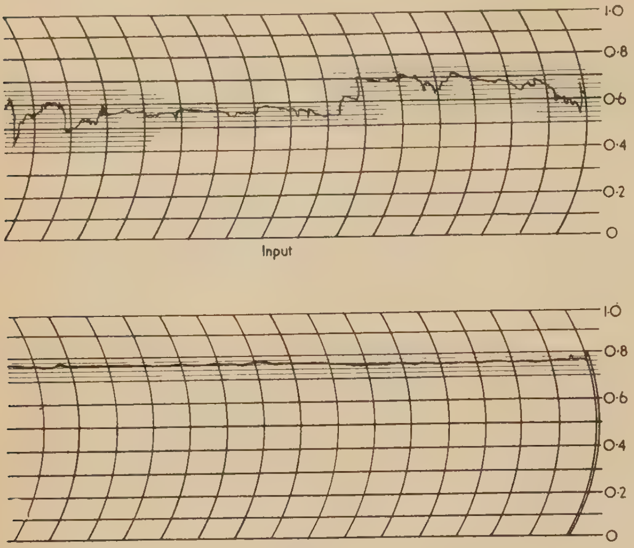

Fig. 3. The stabilizing effect of the r.m.s. controller on the output of an unstable oscillator

Direct current through the heater winding is controll V_3, and this valve receives its grid voltage from C whi charged through V_2 to the peak value of the a.c. wavef V_1 provides voltage amplification and isolation of the fying circuit from the attenuator. Any tendency for E increase results in a more negative voltage across C. reduces the cathode current of V_3 so that the resistan R_t is increased, tending to stabilize the amplitude o voltage appearing across R_1. This circuit has proved t

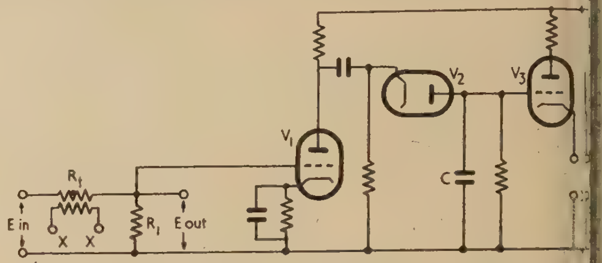

Fig. 4. Modification to the circuit so that the pe rather than r.m.s. voltages are controlled

most useful for stabilizing the amplitude of repetitive p before they are fed to a counter or rate recorder. P forming techniques may, of course, be employed, bu automatic attenuating system has the advantage that it maintain maximum signal-to-noise ratio.

A typical example is the recording of the heart rate d cardiac surgery, where the triggering pulse is taken fro electrocardiograph complex wave after suitable filterin may vary widely in amplitude during the course o operation. The inclusion of the circuit shown in Fig. 4 removed the necessity for amplifier gain adjustments the initial setting up.

Sensitive detector of γ-radiation in liquid or gaseous effluents

By J. G. Mitchell, Associated Electrical Industries Ltd., Aldermaston, Berks.

[*Paper first received* 5 *February, and in final form* 17 *April*, 1959]

The instrument described is a plastic-phosphor scintillation-type detector which can be used to monitor the radio-activity of liquid and gaseous effluents. With liquid effluents, it can detect activities of about $1{\cdot}5 \times 10^{-6}$ μc/cm^3 of 0·7 MeV γ-radiation, and for gaseous effluents, 1/280 m.p.c. of ^{41}A in air. The experimental determination of the optimum sensitivity of the detector system is described and results are given. The system provides a continuous day-and-night record of the activities monitored. Also, it gives automatic warning of dangerously high levels of activity and of a failure in its own electrical system.

Description. The instrument was developed to detect low levels of radioactivity in water and air. It consists of a scintillation type γ-radiation detector, using a plastic phosphor and a photomultiplier, connected, *via* a pulse amplifier, to a ratemeter, which in its turn feeds a recorder and trip circuit.

Activities in liquids. When used to monitor activity in liquids, the scintillation counter and its head amplifier are contained in an aluminium shroud with an internal diameter of 6 in., and this is immersed in a tank of liquid, the cross-section of which is 2 ft square. The overall height of the tank is 2 ft 3 in., the depth of liquid being 1 ft 10 in. In these conditions, $1{\cdot}5 \times 10^{-6}$ μc/cm^3 of 0·7 MeV γ-activity in the liquid will give a counting rate equal to background.

Activities in gases. To monitor the activity in a gas, the same scintillation head, in a similar shroud, modified to permit wall or pole mounting, points upwards and measures the activity in a hemisphere of the gas. In these conditions, an effectively infinite hemisphere (of about half a mile rad of ^{41}A, at a concentration corresponding to 4 × 1 maximum permissible concentration, will give a coun rate equal to background. The maximum permiss concentration (m.p.c.) of an isotope in air or wate that concentration which, because of ingestion or di radiation, can lead to the maximum permissible dose b received by the whole body or any critical organ. (1 m ^{41}A $= 5 \times 10^{-7}$ μc/cm^3 and is a direct radiation hazard.

The plastic phosphor. The phosphor used is a pl phosphor, type N.E. 102 (by Nuclear Enterprises Ltd. the form of a cylinder 5 in. in diameter and a length depen on application. The greatest length of the phosphor cyli which has been used is 5 in. A plastic phosphor is c siderably cheaper than a sodium-iodide (Tl) crystal, part larly in the larger sizes. Further, it need not be encapsul and can be machined to any size. It does not have g diation resolution, but that is not important in this cation. The light pulse from it for a given γ-ray energy ıaller than that from a sodium-iodide (Tl) crystal; pro-l there is adequate gain in the rest of the instrument, this ly important in so far as it affects the ratio of signal to omultiplier-noise.

otomultiplier noise. Photomultiplier noise results from nal electrons from the photo-cathode causing voltage s at the collector. The pulses are small, but if the tive differentiating time constant is long, they can build nto a large pulse which will be counted on the ratemeter. riments using a detector head with and without a phor show that the counting rate for photomultiplier-noise can be made less than 1% of the normal back-nd rate, with the conditions in which the detector will sed.

eration. The light pulses from the phosphor are cted by a photomultiplier tube, type 6099A (by E.M.I.), ted for its low-noise characteristics, which works at a ctor voltage of 800–1000 V. Pulses from the collector o a head amplifier with a gain of about five times, the ode-follower output of which is connected to the main lifier (see Fig. 1). The amplifier has a gain of 1700, a d-width of 2·5 Mc/s, and a differentiating time constant 1 μs which is necessary to produce a low counting rate the photomultiplier-tube noise. Attenuation of 20 dB is vided, in steps of 2 dB. The output from the amplifier d to a ratemeter, type N522B (by E. K. Cole), which vides h.t. supplies to the head and main amplifiers, and t. supplies to the dynode chain of the photomultiplier. ause the e.h.t. supply can give only a low current, the ode chain has a high impedance of the order of 18 MΩ. he ratemeter feeds a recorder to provide continuous rds of activity and high- and low-level trip circuits. The ı-level trip operates when a certain level of activity is cted and can initiate the appropriate action (operate a e which diverts water from one drain to another, for nple). The low level trip operates when the signal is w a certain level; this is set between zero and the normal kground of the instrument. Hence most faults lead to or other of the trip circuits operating. Because the al from the ratemeter to the recorder may travel several dred feet close to a mains-carrying cable, it passes through a filter which also attenuates the signal to a level suitable for the 100 mV recorder. To ensure that mains-voltage variations do not affect the instrument, the power supply for the ratemeter, amplifier, and head amplifier comes from a constant-voltage transformer. The electronic circuits are, however, being redesigned, so that in future a constant-voltage transformer may not be needed.

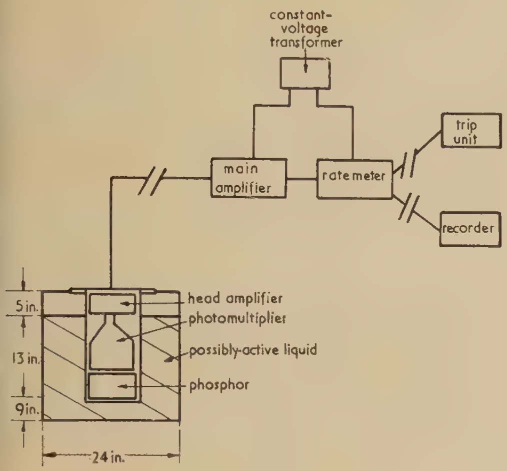

Fig. 1. Block diagram of apparatus

ables from head amplifier to mean amplifier and from ratemeter to recorder can be up to 250 ft long.

To prevent radioactive contamination of the monitor shrouds, they are painted with chemical-resistant paint and enclosed in polythene bags. The galvanized water tanks will be cleaned periodically to prevent build-up of activity.

CALIBRATION AND SENSITIVITY TO LIQUID EFFLUENT

To simulate the activity of mixed fission products, which have an average energy of 0·7 MeV, ^{137}Cs was chosen as in 82% of disintegrations it emits a 0·66 MeV γ-ray. The activity of the ^{137}Cs source was measured absolutely to ±5% using a 4π β-counter.

Experimental procedure. The monitor was placed centrally in a 2 ft square tank so that the phosphor was 9 in. from the bottom of the tank and the depth of demineralized water was 22 in. The electronic equipment was as described above, except that no recorder or trip circuit was used, and two scalers in cascade were fed from the main amplifier.

Results. A series of 40 s counts was made at various settings of the photomultiplier voltage, amplifier attenuation, and discriminator bias to determine the background counting rate of the instrument. The ^{137}Cs was then added to the water in progressively larger quantities to simulate activity levels from 10^{-6}–10^{-4} μc/cm^3, and readings were taken at each specific activity level. Graphs plotted from these results showed the level of activity at which the true signal was equal to background for various settings of the monitor. (The true signal is the total signal minus background at the

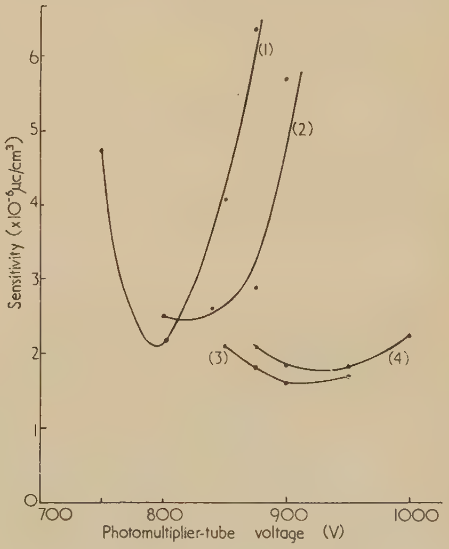

Fig. 2. Variation of sensitivity with photomultiplier-tube voltage

Sensitivity is measured as activity at which true counts equal background.

(1) discrim. bias = 6 V; amp. atten. = 0 dB
(2) discrim. bias = 8 V; amp. atten. = 0 dB
(3) discrim. bias = 6 V; amp. atten. = 6 dB
(4) discrim. bias = 8 V; amp. atten. = 6 dB

same setting.) Sensitivity curves for true signal equal to background are plotted in Fig. 2 for four different settings. The best sensitivity is obtained with a photomultiplier e.h.t. voltage of 900 V, a discriminator bias of 6 V, and an amplifier attenuation of 6 dB.

Calculation of the sensitivity of the monitor. The monitor is calibrated, in terms of activity, assuming one γ-ray is given off per disintegration. Hence, adjustment for the 82% γ-ray abundance of ^{137}Cs is made in the calculation. In Fig. 3, in which true counting rate per second is plotted against such an activity, it is found that a true counting rate equal to background is produced by $1\cdot5 \times 10^{-6}$ μc/cm^3. In interpreting the reading of a given monitor, however, it must be borne in mind that mixed fission products give less than one γ-ray per disintegration, and that the exact number varies with the reactor history and the time lapse between the cessation of fission and sampling.

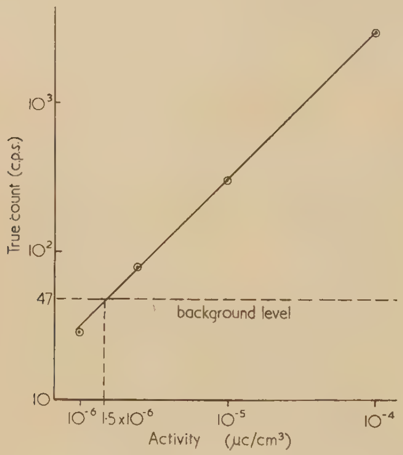

Fig. 3. Variation of count rate with activity

Photomultiplier-tube voltage = 900 V. Amplifier attenuation ≐ 6 dB. Discriminator bias = 6 V.

GASEOUS EFFLUENT

^{41}A of half-life approximately 100 min is produced by neutron irradiation of air in the vicinity of a reactor, and may be discharged to the atmosphere through a chimney. In a research reactor, when neutron beams are being used, the quantity of ^{41}A produced may be relatively large and air monitors are usually required at points around the reactor, to measure activity in the air and to provide a warning if any excessive activity is detected. The equipment will, of course, also provide a warning signal if some other unusual source of radioactivity is detected (fission products in the atmosphere in the region of the reactor, for example).

Sensitivity. The scintillation head described above is used. Fig. 4 shows a trace given on the recorder chart with the following experimental conditions. *A* is the trace when a 4·5 mc source of ^{60}Co is placed 20 m from the detector; this produces a radiation level at the detector equal to that produced by a 100 m radius hemisphere of ^{41}A, centred on the detector, at a concentration of 10^{-1} m.p.c. *B* is the trace when the ^{60}Co source simulates a 10^{-2} m.p.c., ^{41}A hemisphere of 100 m radius. *C* corresponds to a 10^{-2}, ^{41}A hemisphere of effectively infinite radius (about $\frac{1}{2}$ mile). ^{60}Co was use simulate ^{41}A, since the γ-ray energies of the former (1·17 and 1·33 MeV) are very similar to that of ^{41}A (1·29 M

The true counting rate is equal to background when radiation level at the detector corresponds to that w would occur if the unit was surrounded by a hemisphe cloud of ^{41}A, of radius 100 m, at a concentration of m.p.c. The corresponding concentration for an effecti infinite cloud of ^{41}A is 1/280 m.p.c., the radiation leve the detector for both being 2·5 $\mu r/h$.

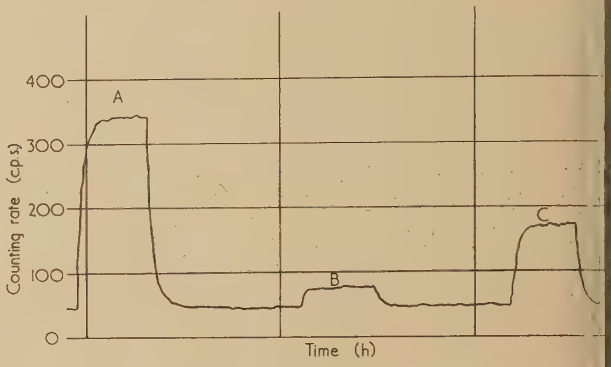

Fig. 4. Chart from air-activity experiment

A, ^{60}Co simulating 10^{-1} m.p.l. ^{41}A in 100 m-radius hemisphe
B, ^{60}Co simulating 10^{-2} m.p.l. ^{41}A in 100 m-radius hemisphe
C, ^{60}Co simulating 10^{-2} m.p.l. ^{41}A in an infinite hemisphere

Stability and background γ-radiation. The instrumen proved very stable when used to record background acti for periods up to several weeks. The few major fluctuat have occurred during rain and have probably been cau by radioactive "wash-out". Also, there is natural diu variation caused by the difference in the ground-level c centration of radon at night and during the day.(3) At time has a chart fluctuation been recorded which has bee large as the normal background. Rain "wash-out" has t on occasion 50% of background while the diurnal varia has been ±5% about the mean.

ACKNOWLEDGEMENTS

The author is indebted to Mr. B. Millar for his help the design of the electronic circuit, to Dr. J. Young for assistance in calibrating the ^{137}Cs source, to B. Lovejoy A. Nordbodden for their help in carrying out the experime and to Dr. T. E. Allibone, Director of the Research Labo tory, Associated Electrical Industries, for permission publish this paper.

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New type of search coil for metal-pipe location

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[*Paper first received* 26 *February, and in final form* 12 *May*, 1959]

A method of tracing metal pipes, involving the amplification of the voltage induced in a special type of search coil by transient currents injected into the pipe, is described. The search coil consists of two identical flat coils mounted side by side in the same plane, and so connected that the output voltage is equal to the difference of the voltages induced in the two coils. An audible signal is obtained in headphones after amplification of the output voltage. It is found that, with this twin coil system, the signal strength varies approximately as $1/R^2$, where R is the perpendicular distance from the pipe to the search coil, and that a more reliable performance is obtained compared with the usual single type of search coil.

re the positions of concealed metal pipes are unknown, frequently necessary to use some instrument to find them. ough a metal detector can be used for this purpose, culties often arise because of the presence of metal cent to the pipe. Also, most metal detectors cannot be to find pipes buried deeper than about one metre. ther method is therefore usually employed in which es of electric current are transmitted along the pipe to raced by connecting a buzzer between a point on the and an earthed terminal. If a search coil is used in unction with a portable amplifier and a pair of headnes, an audible signal can be obtained as the pipe is roached. The exact position of the pipe is found by ling the axis of the coil vertically, the signal strength ng to zero when the centre of the coil lies directly over pipe.

his method can sometimes give misleading results because signals induced in the search coil by current from the zer flowing in:

) the wires running from the buzzer to the pipe and earthed terminal;
) pipes connected to the one being followed;
) the ground.

ne other effects can also give false indications.

SEARCH COIL

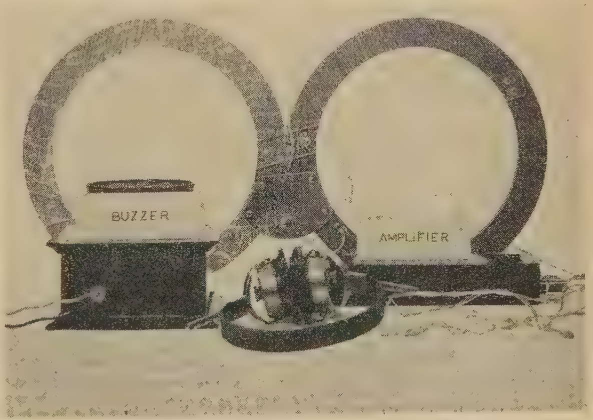
n an attempt to overcome some of the difficulties listed, a erent type of search coil has been used, with which a ch better performance has been obtained. This search , instead of being a single flat coil, is constructed from identical flat coils mounted side by side in the same ne. These are connected in series so that the output age is equal to the difference of the voltages induced in two coils. This arrangement has the property that the put voltage is always zero when placed in a uniform, nging magnetic field, the voltages induced in the two coils tually cancelling each other. If it is supposed that the s are circular and that they are held so that their plane tains the line of a long straight pipe carrying current ses of constant amplitude, then it can be shown that, if coils are moved without rotation, the output voltage es approximately as $1/R^2$ for values of R very much ater than the separation of the centres of the coils. (R ne perpendicular distance from the pipe to the mid-point he line joining the centres of the coils.) On the other d, the output voltage from a single flat coil of wire, ilarly held, varies approximately as $1/R$ for values of R much greater than the dimensions of the coil. (Here efers to the distance from the centre of the coil to the pipe.) It is thus clear that the signal strength from the double system will decrease much more rapidly with distance, compared with the usual type of search coil. Also, it is found in practice that the difficulties listed under (*a*), (*b*) and (*c*) are largely eliminated when this double arrangement is used.

Use of instrument. When searching for a straight pipe, along which transient currents are flowing, the coils are held close to the ground with their plane horizontal. After the position of the pipe has been roughly determined, its direction is found by rotating the coils about a vertical axis until silence is obtained in the headphones. The line joining the centres of the coils is then parallel to the pipe. If the system is now rotated through 90 deg., the plane of the coils being kept horizontal, it will be found that as the coils are moved parallel to the line joining their centres, two silent positions will be obtained on opposite sides of the pipe. Because these positions are both equidistant from the pipe, the line of the latter can be ascertained. By measurement of the displacement of the coils between these two silent positions, the depth of the pipe can be calculated. For two circular flat coils in contact, the depth is found fairly accurately from the relation:

$$h = (x^2 - \frac{7}{4}a^2)^{1/2}$$

where h is the depth of pipe, $2x$ is the distance between the two silent positions, and a is the radius of the coils. When h is very much greater than a, as is easily obtained in practice, h is approximately equal to x.

This equation for the depth is rather difficult to obtain, but it has been checked experimentally and found to give the depth within the limits of error.



Photograph of search-coil equipment

DETAILS OF EQUIPMENT

The size of the coils and the number of turns required to obtain an audible signal of sufficient intensity depend largely on the gain of the amplifier used. Satisfactory results have been obtained by using coils 25 cm in diameter, each of 700 turns. The coils were mounted as described above and connected to a two-transistor amplifier *via* a switch. In one position of the switch, the input voltage to the amplifier is equal to the difference of the voltages induced in the two coils, whereas in the other it is equal to the sum. In this latter position the two coils behave effectively as one. The pipe may therefore be located in the two different ways described above. When the difference position of the switch was used, the signal rapidly became inaudible as the coils were moved away from the vicinity of the pipe, in the sum position, a signal could be heard at distanc up to about 15 m from the pipe.

A photograph of the equipment is shown in the fi The search coil, together with the amplifier, headphones buzzer can all be seen.

It will be apparent to the reader that many types of do coil systems can be used for pipe location with results si to those described here. The particular case of circular has been mentioned merely as an example.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. R. Fearnley for structing the coils used in these experiments.

Vibration amplitude meter using moiré-fringe technique

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[*Paper first received* 25 *March, and in final form* 26 *May*, 1959]

The instrument described, though not being the answer to all vibration-measuring problems, has characteristics which make it ideal for the measurement of vibration amplitudes at frequencies below 50 c/s and for the calibration of other transducers. Also, because its frequency range extends down to zero, the instrument can be used to detect and measure small displacements.

The production of relatively inexpensive linear-diffraction gratings by a process developed at the National Physical Laboratory(1) and their application to measurement and control systems,(2,3) using moiré-fringe techniques, suggested the development of a vibration measuring device having the following characteristics:

(1) Direct indication of peak-to-peak amplitude of vibration;
(2) frequency range 0–4 kc/s;
(3) no dynamic calibration necessary because the pitch of the grating is the basis of the measurement.

An instrument of this type, useful both for calibrating accelerometers and measuring vibration of mechanical systems, was made and has been in use now for several months. The principle on which the instrument is based is the production of interference bands or moiré fringes from two gratings placed face to face with their lines not quite parallel.(4) Relative motion between the gratings in a direction at right-angles to the lines produces motion of the fringes such that, when the gratings move through one line pitch, the fringes move through one fringe pitch.

If a pair of gratings is illuminated by collimated light, then the distribution of light intensity across the fringe pattern is approximately sinusoidal, and four photocells can be arranged to receive light signals in quadrature. The amplified outputs of the photocells applied to the plates of a cathode-ray tube produce a circular trace for continuous motion of the gratings and an arc of a circle for vibratory motion. The angle subtended by the arc is directly proportional to the amplitude of vibration and when the arc just closes into a circle, the peak-to-peak amplitude is equal to the pitch of the gratings. Hence vibration amplitudes can be measured in terms of the known pitch of the gratings down to approximately 0·05 of the pitch and up to a value depending on the maximum number of complete circles which can be identified on the trace. With 2500 lines/in. gratings, this gi discrimination of 0·000 02 in.

DESCRIPTION

Fig. 1 is a photograph of the instrument showing the units, optical and electronic, which are interconnected by cables.

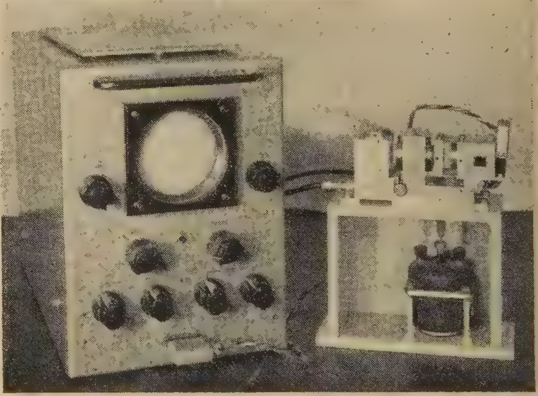

Fig. 1. Vibration-amplitude meter

Optical unit. Fig. 2 is a sectioned drawing of the opt unit which is constructed mainly of aluminium alloy. essential components are a lamp, a collimating lens, a of gratings, a combined four-element prism and lens, a and four photocells. The optical system is slightly com cated by the diffraction in the gratings which results i spectrum on which is superimposed the moiré fringes. Th have a different phase for each wavelength of light through the spectrum and so observation of the whole fringe fi ws no visible fringes, or very weak ones. So the photo- s are constrained to view only that portion of the first er spectra corresponding to their peak spectral response the optical system somewhat resembles a spectrometer.

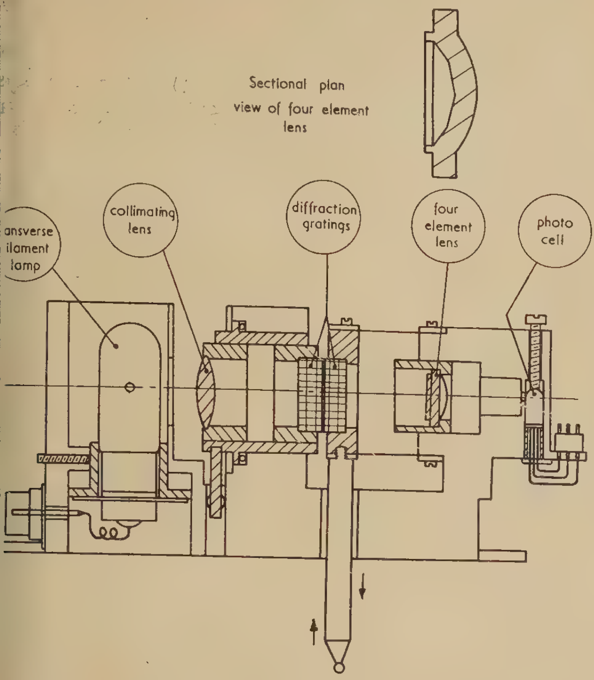
Sectional plan view of four element lens
ansverse ilament lamp
collimating lens
diffraction gratings
four element lens
photo cell

Fig. 2. Optical unit of vibration amplitude meter

ctly, the incident and exit light paths should make equal ll angles with the normal to the gratings, that is, the dition of minimum deviation, but to simplify the chanical assembly, only the incident light path is angled.

The light source consists of a low-wattage projection lamp and an aspherical collimating lens. The lamp is fitted in a sliding holder so that the transverse filament can be moved about the optical axis, thus altering the angle at which the light is incident on the gratings. The fixed grating is mounted in a holder which can be rotated about the optical axis by means of a lever and screw arrangement. This provides a sensitive means of adjusting the small angle by which the lines on the gratings are crossed. The holder can also be adjusted axially to set the gap between the gratings.

The moving grating is mounted in a block cantilevered out from the main body on two parallel spring strips, the vibratory motion being imparted to the block through a ball-ended stylus. This suspension ensures that, for small displacements, the motion takes place in a straight line. Without this constraint, components of the motion in directions other than the desired one would cause errors. For example, change in the thickness of the gap between the gratings causes a change in radius of the trace. In addition, because the optical system is not in the condition of minimum deviation, an error arises from phase shift of the fringes.

The fringe field is focused on to the photocells by the combined four-element prism and lens. The light falling on each facet is deviated and focused on to a separate photocell, the geometry of the arrangement being governed by the physical size of the cells. To bring the signals into quadrature, the fringe pitch is made equal to the combined width of the four facets by adjusting the crossed angle between the lines on the gratings. This adjustment is effected in practice by applying to the moving grating a vibratory motion with an amplitude approximately equal to the pitch of the gratings and observing the degree of circularity of the trace on the c.r.t. There are now four spectra focused on the plane of the photocell apertures which are approximately 0·060 in.^{2} and act as slits to allow only light of the required wavelength to reach the cells. These are phototransistors and

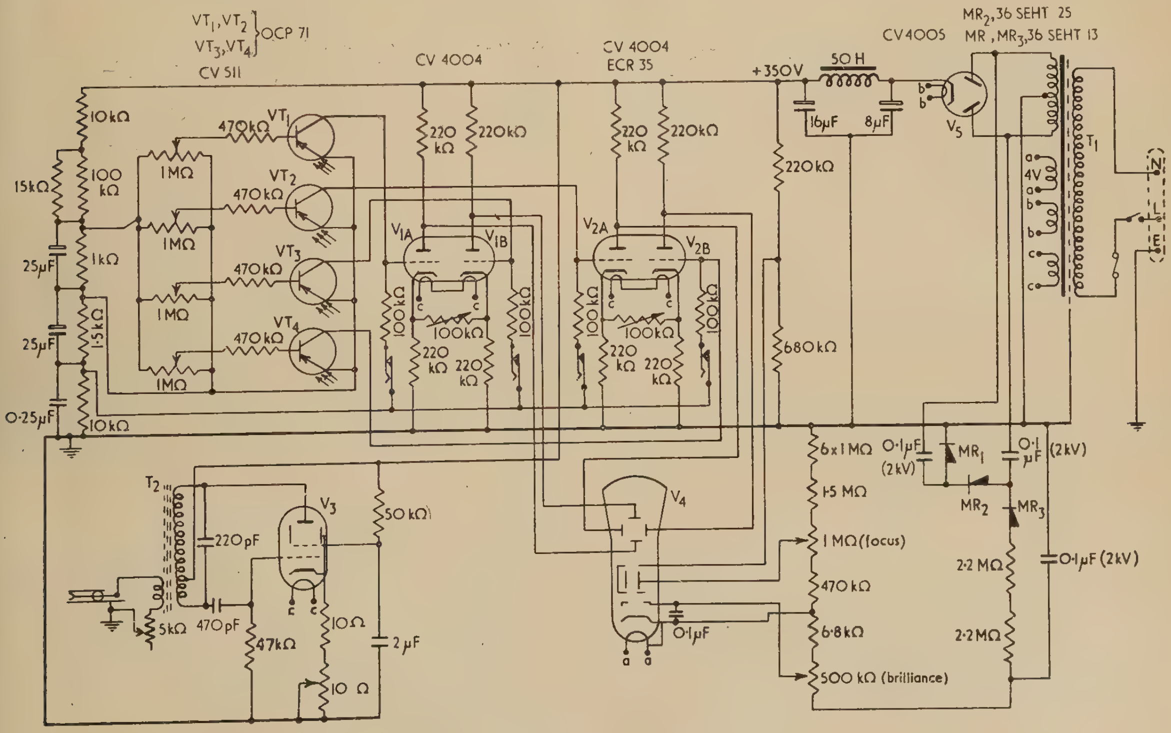
VT1,VT2 VT3,VT4 OCP 71
CV 511
CV 4004
CV 4004 ECR 35
CV4005
MR2,36 SEHT 25
MR, MR3,36 SEHT 13
+350V
50 H
16μF
8μF
V5
T1
4V
N
L
E
a
b
c
10kΩ
15kΩ
100 kΩ
25μF
1kΩ
1·5kΩ
0·25μF
10kΩ
VT1
VT2
VT3
VT4
470kΩ
1MΩ
220 kΩ
220kΩ
V1A
V1B
V2A
V2B
100kΩ
220 kΩ
c
220kΩ
680kΩ
6×1 MΩ
0·1μF (2kV)
MR1
MR2
MR3
0·1 μF (2kV)
1·5 MΩ
1 MΩ (focus)
470 kΩ
6·8kΩ
500 kΩ (brilliance)
2·2 MΩ
0·1μF (2kV)
V4
0·1μF
a a
T2
V3
220pF
50 kΩ
5kΩ
470pF
47kΩ
10Ω
2μF
10 Ω

Fig. 3. Electronic unit of vibration amplitude meter

have peak spectral response in the near infra-red region, $1 \cdot 5\ \mu$.

Electronic unit. Fig. 3 is a circuit diagram of the electronic unit. The four phototransistors derive their energizing and bias voltages from a resistance chain across the +350 V line. The base bias voltage is adjustable for each phototransistor to set the operating point and this also provides a convenient method of shifting the trace on the c.r.t., for centring purposes. The signal voltages developed across the phototransistor load resistors are directly coupled to the grids of two double triodes, V_1 and V_2, so that each valve receives a pair of signals in push-pull. Control of the gain in each stage is by means of a variable resistor across the cathodes. The output voltages developed across the anode loads are directly coupled to the deflexion plates of the c.r.t., V_1 to the Y-plates and V_2 to the X-plates.

The electrode supply voltages for the c.r.t. are derived from resistance chains across the +350 V and −700 V lines, the final anode voltage being set approximately equal to the mean anode voltage of V_1 and V_2. V_3 is a power oscillator which supplies current to the lamp in the optical unit at a frequency of 50 kc/s, that is, at a frequency the period of which is small compared with the thermal time constant of the lamp filament. Hence no unwanted signal at the lamp-supply frequency appears in the photocell output. The oscillator is a series-fed Hartley circuit with control of the lamp current by means of a variable cathode resistor. The power supplies consist of a conventional full-wave circuit supplying +350 V and a balanced voltage-multiplier circuit supplying −700 V, both derived from one centre-tapped winding on the mains transformer.

The electronic unit is housed in a portable metal case with provision for mounting, in front of the c.r.t. screen, graticules divided into sectors as an aid in estimating the length of the arc. The graticules also carry two concentric circles to help in centring and adjusting the trace for best circularity.

PERFORMANCE

Some trouble was experienced at first because of variations in mains voltage affecting mainly the intensity of the lamp in the optical unit, but this was cured by running the equipment from a constant-voltage transformer. After a few minutes warming up, the equipment now remains stable throughout a whole day's working.

The calibration of the instrument depends on the pitch of the gratings and the angle which the direction of motion makes with the lines on the gratings. For most practical purposes, the nominal pitch of the gratings can be accepted as the calibration provided the lines on the gratings are normal to the direction of motion within ±5°. For more accurate work, a static calibration can be made by placing a series of slip gauges between the stylus and a fixed anvil and noting the deflexions of the spot on the c.r.t. Gratings, the measured pitch of which, normal to the lines, is less than the nominal or desired pitch, can be corrected within limits by setting them with their lines at an angle to the direction of motion.

The useful frequency range of the equipment is limited by two factors. First is the frequency response of the phototransistors, the cut-off frequency being quoted by the makers as 3 kc/s. However, because the only effect of reducing the amplitude of the signals is to reduce the diameter of the circular trace, whilst the angle which a given arc subte remains constant, the equipment can be used at frequen above this value. The second factor is the effect of resona in the spring-strip suspension of the moving grating. T trouble can be overcome in a number of ways such as adj ing the stiffness of the suspension to place its resonance o side the required frequency range. The prototype instrum was adjusted to give a suspension resonance of approxima 100 c/s. Alternatively, the suspension can be dispensed w altogether and the moving grating fixed directly to vibration source or to a rigid extension fixed to the sou In this case, the vibration must be restricted to motion i straight line normal to the lines on the grating beca components in other directions will give rise to errors.

Two other possible sources of error are variation ambient temperature and the effects of vibration on optical unit itself. The components most susceptible temperature changes are the phototransistors and the eff are a change in output amplitude and distortion of circularity of the trace. This is immediately evident on c.r.t. and can be rectified by adjustment of the gain and s controls. If persistent trouble from fluctuating ambi temperature is experienced, an improvement can be effec by reducing the value of the phototransistor load resisto The effects of vibration on the optical unit may be clas as primary and secondary. It is essential for accur measurement of absolute amplitudes of vibration that body of the optical unit be rigidly mounted or otherw isolated from the vibration source. If the unit vibrates sympathy with the source, there will be a primary er proportional to the amplitude of this vibration and a possi secondary error from component vibration, notably the la filament and its supports. Inspection of the optics sho that errors from this source would be negligible compa with the primary error. However, one might contemp using the instrument for the measurement of relative am tude of vibration between two members of a system. this case it would be wise to check for the presence secondary error by removing the stylus, locking the mov grating and subjecting the unit to the maximum amplitu of vibration liable to be encountered throughout the requi frequency range. Any secondary error would show up a trace on the c.r.t.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance given Ferranti Ltd., Edinburgh, who supplied the special fo element lens used in the optical unit. The work describ above was carried out in the Mechanisms, Metrology a Noise Control Division of the Mechanical Engineeri Research Laboratory, as part of the research programme the Mechanical Engineering Research Board. It is publish by permission of the Director of the Laboratory.

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Grating spectrophotometer for the Schumann ultra-violet range

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[*Paper first received* 5 *March, and in final form* 28 *May*, 1959]

Constructional and performance details are given of a photoelectric spectrophotometer erected for the measurement of the optical transmittances of small solid specimens, in the range above 900 Å. The instrument incorporates a one-metre radius, 600 lines/mm concave grating, and scanning of the spectrum across the exit slit is performed by a linear movement of the centre of the Rowland Circle. The mechanical and electrical arrangements permit rapid measurements, quick exchange of specimen and the direct reading of transmittance on a 0–100 scale.

ing the last ten years several reports have appeared ng details of the construction and performance of vidual photoelectric scanning spectrophotometers for in the region below 2000 Å. According to the require- ts for wavelength range, light grasp, resolution, dispersion stray-light tolerance, the following considerations are ortant.

rism spectrometers are limited to those employing hetic lithium fluoride or calcium fluoride crystal optics. instruments are useful for some work in the restricted elength range above about 1500 Å, because relatively e apertures and good dispersion can be achieved in a pact assembly. However, resolution as well as wave- th range is limited, currently available crystals are ensive in all but the smallest sizes, and figuring costs are er high. A serious drawback of prism instruments is the of trouble from large amounts of scattered light, though nmond and Price(1) have ingeniously overcome this by dulating the light at the exit slit by vibration of the back ror in a Littrow arrangement.

or most work, use of a concave grating has notable antages. The wavelength range is much wider, extension 00 Å or thereabout offering little difficulty to the more venient form of near-normal incidence mounting. tings of one to three metres radius, of adequate dis- sion and very good resolution are now readily available , moreover, can be made with an efficient blaze in the -order vacuum region. Again, stray light is less trouble- e with a good grating, and, in the region above 500 Å, mechanical scanning arrangement can be simple. A l advantage of the grating is, of course, its practically ar dispersion.

particularly successful one-metre normal-incidence ctrometer described by Tousey, Johnson, Richardson and ran(2) has been used as the basis of a commercial model ird Associates). This is a form of "radius mounting" wyer(3)), in which scanning is achieved by keeping the rance and exit slits fixed on the Rowland circle, and ating the grating on an arm pivoted at the centre of this le. The principal difficulties of the arrangement appear be (*a*) the varying aspect of the grating as seen from the s of both the light source and the detector, (*b*) the need a high-precision worm drive for the grating movement. spectrometer (which is mechanically more complicated) cribed by Robin-Salomond(4) is essentially an Eagle unting with linked rotation and linear motion of the ting.

he foregoing summary, which neglects mention of large- dence-angle spectrometers (Greiner,(5) Namioka(6)), is ended to give perspective to a description of a scanning spectrometer built to satisfy the following requirements:

(1) Spectral range of 1300–2500 Å.

(2) While specialized immediately for rapid measurement of the transmittance of small samples of solid materials, the assembly should be easily modifiable to permit extension of the range to 800 Å, and to allow quick changes in light-source and detector systems.

(3) Direct-reading electronic indication of percentage transmittance of samples.

(4) Immediate resolution of 5 Å, with ready provision for improving this to perhaps 0·2 Å.

(5) Maximum useful-to-stray-light signal ratio.

(6) Compactness and remote-control operation.

(7) Protection of grating from corrosion.

PRINCIPLES OF SPECTROMETER DESIGN

Requirements (1), (4) and (6) can together be satisfied by use of a one-meter concave grating of 600 lines/mm, and (5) indicates that the grating blaze should be about 1500 Å in the first order. The wavelength range indicates use of a normal-incidence arrangement, because larger angles of incidence involve more astigmatism and greater mechanical complexity. For the 5 Å bandwidth it would be quite adequate to fix entrance and exit slits and to scan by simply rotating the grating about a vertical axis through its centre. However, to render the finer resolution of 0·2–0·5 Å available over a range of 1000 Å or more, it is necessary to maintain focus fairly well, that is, to keep both slits and grating

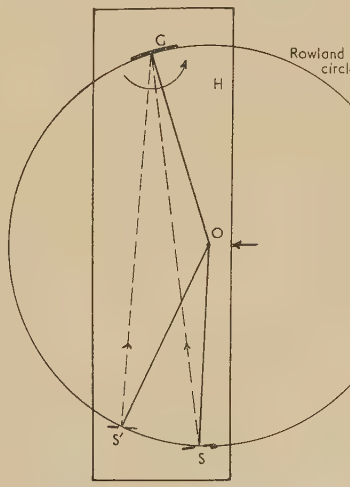

Fig. 1. Principle of mounting

Consultant to U.K.A.E.A., A.E.R.E., Metallurgy Division, well.

on the Rowland circle. This condition is secured, of course, in the radius mounting as used by Tousey *et al.*(2) In the present case, it was thought that the same end might be attained, with less stringent requirements on the accuracy of the grating movement and with avoidance of trouble arising from change of grating aspect at the slits, by arranging matters as illustrated in Fig. 1.

In the diagram, the grating *G* and entrance and exit slits *S*, *S′* are supposed mounted on a girder *H*. The grating is able to rotate about a vertical axis through its centre, and scanning is achieved by joining the grating turntable to the centre *O* of the Rowland circle; sideways displacement of *O* then rotates the grating. The slits *S*, *S′* are similarly joined to *O*, and the three linking rods are pivoted at this point so as to be free to move relatively in the horizontal plane. It is clear that, to be able to move *O* sideways and thus scan at the exit slit and simultaneously keep all three *G*, *S*, *S′* on the Rowland circle, two of these three must be capable of linear movement. Thus, if *S* is fixed on *H*, then *S′* and *G* must be free to move in a direction approximately at right-angles to the displacement of *O*.* In the present case, because of condition (7), it was decided to seal off the spectrometer vacuum from the light source by means of a plate or lens of lithium fluoride. This removed the necessity of making the entrance slit as near "vacuum-tight" as possible. It thus became feasible to have both slits moveable slightly to and from the grating *G*, the latter being fixed in position on *H* but rotatable, of course, about the vertical axis. By arranging for the slit movements (which amount to only a few millimetres when scanning the range 1300–2500 Å) to be directed, as shown by the arrows in Fig. 1, along lines directed at the grating centre, the problem of changing grating aspect is removed. It will be seen that a one-millimetre movement of *O* sideways, with a grating of the type specified, produces a sweep of 67 Å across the exit slit.

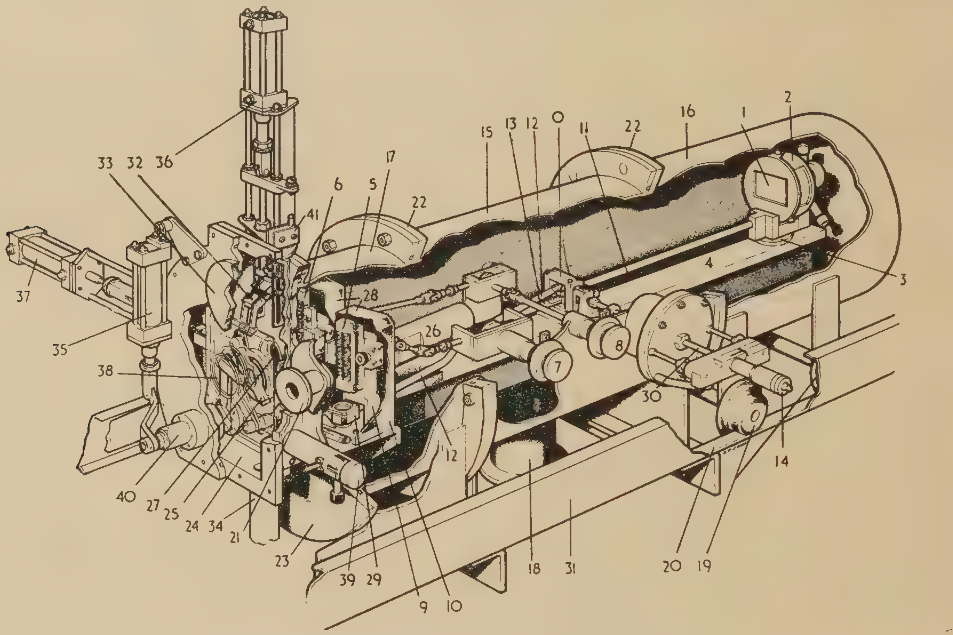

Fig. 2. General view of spectrophotometer

CONSTRUCTIONAL DETAILS OF SPECTROMETE

The manner in which this design was realized is shown Fig. 2. The concave grating 1, seen in its holder 2, ha ruled width of 96 mm and a height of 56 mm; the ruling described as "tripartite" (being divided into three eq portions of slightly differing blaze angles) to allow for alte tion of the angle of incidence across the grating surfa The grating holder 2 is mounted on a conical bearing, lower half 3 of which is bolted to the main T-girder 4. the other end of 4 are seen the entrance and exit slit assemb 5 and 6. Each of these carries four slits of different widt viz., 1·0, 0·5, 0·1, 0·01 mm. Each of these slits can introduced into the light beam from outside the vacu housing by means of Wilson seals, which terminate in knobs 7 and 8. The slit assemblies are held on carriages, which one can be seen at 9; these carriages are mounted bevelled ways 10, and are thus able to slide over a dista of about one inch in the direction of the centre of the grati The radial arms, which link 1, 5 and 6 to *O*, the centre of t Rowland circle, can be seen at 11, 12 and 13. These ro are freely pivoted inside the cage at *O*, which can be driv sideways by means of a shaft 30, which passes through Wilson seal and carries a micrometer screw 14, graduated i 1/400 mm over a distance of 50 mm.

The girder 4 is rigidly attached to the central portion of the stainless-steel vacuum tank; 15 is itself firmly support on a welded framework of angle-iron 31, and carries t diffusion-pump assembly, comprising a two-inch mercu pump, liquid-air trap and baffle-valve. The main pumpi port in 15 can be seen at 18. The end portions, 16 and 1 of the vacuum housing are mounted on wheels 19, a can be run away from 15 on tracks 20, which form t top of the iron supporting framework 31. The thr portions 15, 16 and 17 of the vacuum tank can be bolt together at the flanges 22, the joints being sealed with rubb gaskets.

In Fig. 3 is shown the central section 15 of the vacuu housing, with the end sections removed as explained abov In this way the whole optical assembly is exposed, to enab initial adjustments of grating and slits to be made as lained below.

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* A linkage of this sort has, in fact, been utilized in a spectrograph mounting due to Dowell.(7) In that instrument the grating rotates and moves to and from the slit, about which the plate-holder pivots.

At the left-hand side of Fig. 2, an attempt is made to ibit the rather complicated construction of the working

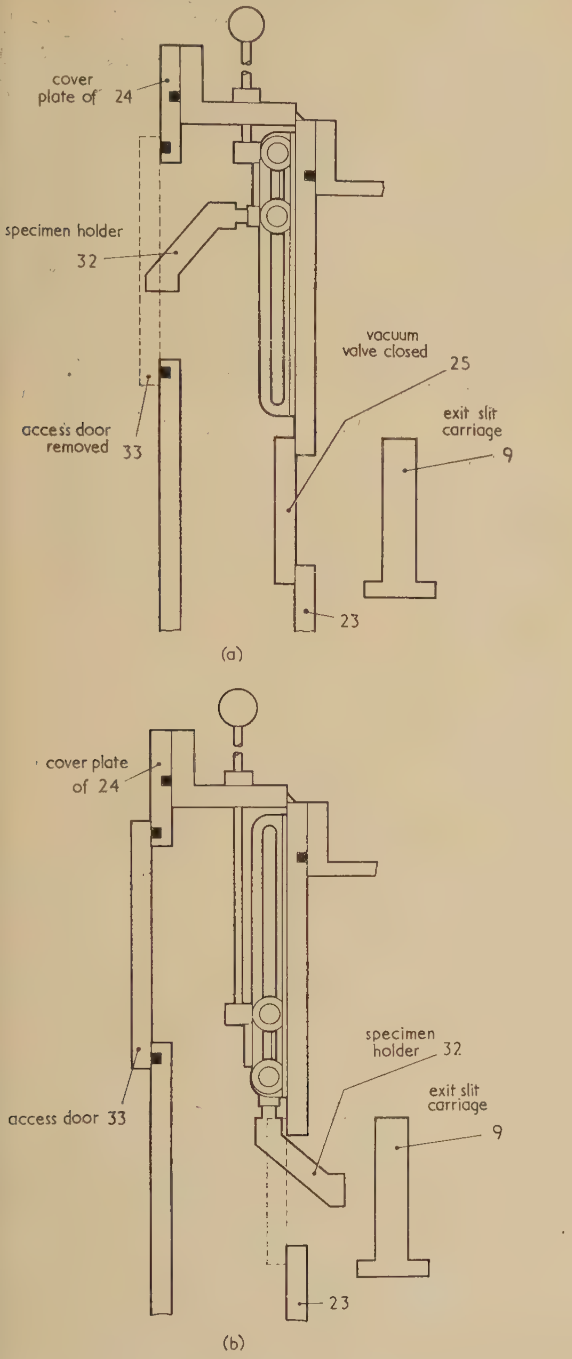

Fig. 2(*a*). Loading position of specimen holder

Fig. 2(*b*). Operating position of specimen holder

d of the spectrometer, where source and detector are ced and solid specimens under test can be introduced o the beam emerging from the exit slit.

To the left-hand flanged end of the portion 17 of the cuum housing, there is attached, by screws and O-ring seal, late 23, of half-inch steel, on which are mounted a short nged pipe 21, for attachment of the light-source, and the specimen chamber 24. The shape of this latter, which is essentially a large flat box, can be seen from Fig. 4, which provides a view of 24, with some of the mechanism removed, and with its cover standing to the left.

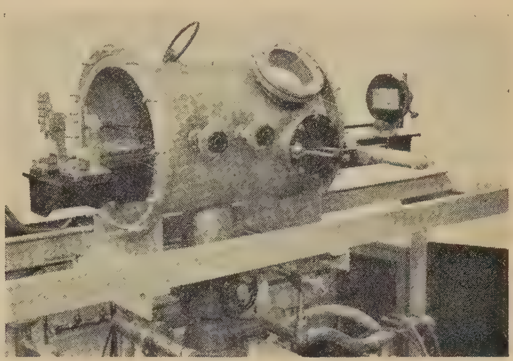

Fig. 3. Spectrometer with end portions of housing removed

The chamber 24 contains a vacuum-gate 25, which can be operated from outside the vacuum. The gate can be seen in a partially raised position inside 24 in Fig. 4. The action of the gate is to cover the aperture 27 in 23 with an O-ring seal; air can then be let into 24 for the exchange of the specimen under test without disturbing the main vacuum.

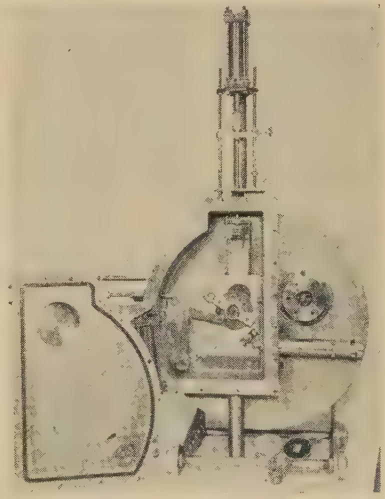

Fig. 4. Spectrometer with specimen chamber open

The way in which a solid specimen is introduced into the exit beam can be understood from Fig. 2, supplemented by the line diagrams in Figs 2(*a*) and 2(*b*). The specimen holder 32 consists of a pair of parallel arms, spring-loaded towards each other to form a small vice able to accommodate specimens of varying size. Access to the specimen holder is achieved, as in Fig. 2(*a*), by releasing the vacuum inside 24, with the gate 25 closed, and then removing the cover plate 33. When a specimen has been inserted in 32, and the cover 33 replaced, 24 is exhausted through the bypass line 34 to the roughing pump, and the gate 25 opened by means of the remotely-controlled, electromagnetically-operated, compressed-air cylinder 35, which is connected to the gate mechanism *via* a Wilson seal 40. The specimen can now be moved alternately in and out of the exit beam by similar operation of the compressed-air cylinder 36. It will be seen from Figs 2(*a*) and 2(*b*) that, in addition to its vertical displacement, the vice 32 suffers a swivelling movement, thus passing the specimen through the aperture 27 to a position close to the exit slit. This feature is important when samples of small width are concerned. A limit switch 41 prevents closing of the gate 25 unless the vice 32 is in its raised position, thus protecting the specimen and its holder from damage.

Two other features of the mechanism inside the chamber 24 remain for mention. At 37 is seen a compressed-air cylinder for insertion of a shutter between the aperture 27 and the face of the photomultiplier detector (the latter has been omitted from Fig. 2 for the sake of clarity). At 38 is seen a pair of filter holders, operated manually from outside the vacuum housing at 39. By this means, either one or both of a pair of filters can be inserted in the exit beam, facilitating estimates of the spectral distribution of stray light and specimen fluorescence.

Stray-light baffling. Care was taken to reduce as far as possible the level of the stray light reaching the photomultiplier detector. The most common procedure, in the past, has been to install metal diaphragms with matt-black painted surfaces. Though often fairly effective, there is no doubt that such screening produces an amount of diffusely scattered radiation inside a spectrometer, which is impossible to control and liable to produce troublesome illumination of the detector. A better method, in principle, appears to be that adopted by Tousey *et al.*,(2) who used baffles of a densely black glass. The basic idea is that any light coming back from the surface of such a diaphragm can be sent in a specific direction to fall on a similar surface; after a few such traversals the residual intensity becomes negligible.

The baffling system in the present instrument was accordingly devized by first removing the portion 16 of the housing, and illuminating the widened entrance slit with a compact source-type high-pressure mercury lamp. After locating the positions of the zero order and the longer wavelength spectra of the first and higher orders, suitably shaped pieces of polished black plate glass were inserted at appropriate positions inside the sections 15 and 17 of the housing, these diaphragms being held by clips to the girder 4, for the most part. After a few trials, as will later appear, the stray-light level was made quite low. Most of the residual stray radiation undoubtedly arises from the grating surface itself, and has to be tolerated.

In addition to the black-glass baffling described, a set of small blackened-metal diaphragms was used to define the light beam between entrance slit and grating; this system of diaphragms is held in a tube 26 which can be seen in Fig. 2. Finally, to avoid leakage of light around the slit assemblies 5 and 6, each was enclosed in a housing 28 of blackened sheet metal, with a tubular projection extending inside the flanged tube 21 and exit aperture 27 respectively.

ADJUSTMENT OF SPECTROMETER

Though a full description here of the finer mechanical details of the spectrometer would require prohibitive space, these have been designed so that the following adjustments can be made readily and reliably:

(i) Rotation of the grating holder 2 independently about the normal and horizontal and vertical tangent lines at the grating centre.

(ii) Rotation of the slit assemblies 5 and 6 to bring entrance and exit slits both parallel to the grating ruling.

(iii) Variation of the lengths of the links 11, 12 and which effectively form Rowland-circle radii. For this adjustment is made by the simple slackening retaining screw on the base of the grating holde For 12 and 13 the adjustment is made with a calibra eccentric cam, as shown at 29.

To bring the spectrometer into strict focus over the wh working range, the end portions 16 and 17 of the housing removed, the entrance slit is illuminated by a source giv a sharp-line spectrum, and the exit slit is viewed in a l power microscope clamped horizontally. The visible ima in zero and first orders can then be viewed alternately in exit slit by sideways displacement of *O*—which is, at this sta conveniently uncoupled from the micrometer drive 14— simple systematic adjustments of the types under (i) to above enable the focusing to be achieved very quickly. ends 16, 17 of the housing are then replaced, light source detector attached to the appropriate fittings of 17, and apparatus exhausted.

LIGHT SOURCES AND DETECTOR SYSTEMS

The most generally useful light source has been the posi column of a heavy-current hydrogen discharge tube, which constructional details are shown in Fig. 5. discharge between the water-jacketed aluminium anod

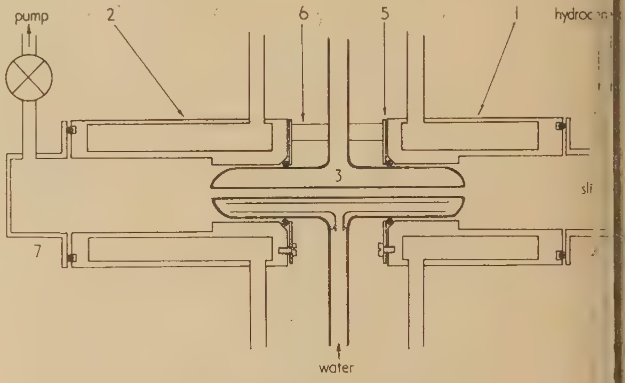

Fig. 5. Hydrogen discharge tube

and cathode 2 is constricted within the inner (4 mm bo tube of the water-cooled fused-quartz piece 3. The joi between the electrodes 1, 2 and the outer wall of 3 are m vacuum-tight by O-rings pinched into contact by me retaining rings 5, and the electrodes are held apart by th Perspex posts 6. A point of obvious importance is selection of a piece of fused-quartz tubing for the outer w of 3 which has a good surface finish and uniformity. glass extensions 4 and 7 provide for pump connexion hydrogen inlet. To enhance the intensity of the molecu spectrum of hydrogen, the inner wall of the quartz constrict is platinized.

This discharge-tube runs stably at currents as high 1·5 A and, when used with a spectrograph instead of spectrometer, its brightness can be further increased raising the current to 3 A, the tube then showing so flicker. When used with the spectrometer of this article, discharge current has usually been restricted to 0·7 A, lack of a rectifier giving a larger current.

The radiation detector most often employed at the e slit has been a photomultiplier, type 6256 (by E.M.I. Ltd This tube is of the "end-window" pattern (the window be fused-quartz) and possesses a one-centimetre-diameter tocathode surface, and thirteen stages. For the region w 1650 Å, the window material absorbs strongly, and it ecessary to sensitize the photomultiplier to shorter wave- ths by depositing on or close to the end-window a layer luorescent substance. Following the work of Johnson, tanabe and Tousey,(8) layers of sodium salicylate deposited the photomultiplier face have been used. In the region ve 1650 Å, the quartz-window photomultiplier is con- rably more sensitive without such a layer (compare with ıkelman and Lock(9)). Occasional trials have also been le of similar-pattern E.M.I. tubes with glass windows sensitized with salicylate.

nteresting results have followed trials of demountable tomultipliers, having dynode assemblies of beryllium–per (Allen(10, 11)), and photocathodes of gold foil. The ice of gold for this purpose was made following the high ntum yield reported by Walker, Wainfan and Weissler,(12) because of the chemical stability of the metal. As lained below, this type of detector has proved con- erably more sensitive at short wavelengths than the cylate-sensitized conventional multiplier, and also negli- ly affected by stray light.

Mounting of the E.M.I. photomultipliers on the spectro- ter is made very simply by placing the end window against O-ring held in a circular groove surrounding an aperture he cover of the specimen chamber 24 (Fig. 2), this aperture ng opposite the hole 27 through which the exit-beam erges. On evacuation of the instrument, the photo- ltiplier is held in position by atmospheric pressure. rrounding the photomultiplier is a brass screening cylinder, ich also contains the dynode resistor chain; the cathode 1 collector leads are brought out through Plessey sockets the back of this cylinder.

The beryllium-copper photomultipliers have been mounted ferently, being suspended inside a glass envelope, the front nged end of which is pressed against the O-ring in 24. e photomultiplier is then evacuated through the aperture 24 together with the spectrometer by the main pumping tem. These photomultipliers have been found to function ll at residual gas pressures as high as $4 \cdot 10^{-5}$ mm.

ANCILLARY ELECTRONIC APPARATUS

\s mentioned above, a basic requirement was that the centage transmissions of solid samples should be directly icated on a scale. This has been achieved by use of the ctronic arrangement of Fig. 6. The photomultiplier nal is applied to the grid of the electrometer pentode, d as a current amplifier in cathode-follower fashion. The microammeter in the cathode circuit is used as a null-indication instrument by means of the potentiometer circuits shown at the right and left of the diagram. The pointer of the high-quality wire-wound potentiometer 3 moves over a large circular scale graduated 0–100. The system 5 and 7 is used to balance out the deflexion of *A* caused by the photomultiplier dark-current, with the slider of 3 at earth and the pointer at zero. With the photomultiplier fully illuminated at a selected wavelength—that is, the absorbing specimen out of the beam—the pointer of 3 is moved to 100, and the current in *A* returned to zero by adjustment of 1 and 2. When the absorbing specimen is introduced into the exit beam, *A* can be again returned to zero by sliding down 3, and the transmittance of the specimen is read directly on the 0–100 scale, the response of the photomultiplier being linear. If the transmittance of the specimen lies in the range 0–10%, then a switch 4 can be operated to change the full-scale response of potentiometer 3 from 0–100 to 0–10. In this way a percentage transmission of 0·05 can be read on the circular scale.

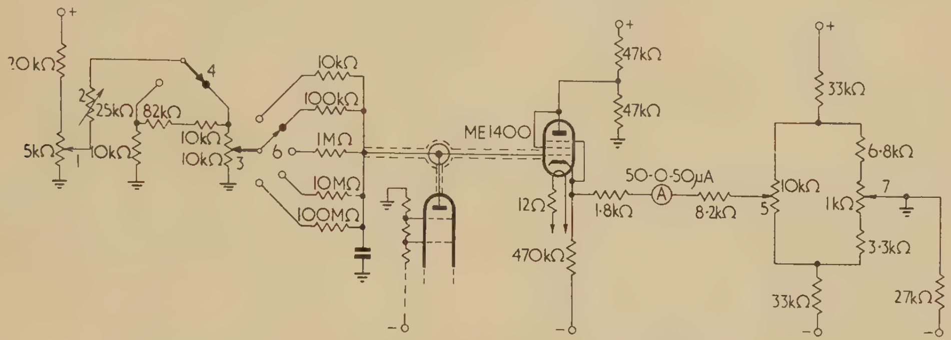

Fig. 6. Electronic measuring circuit for spectrophotometer

The range of photomultiplier currents corresponding to full-scale deflexion of *A* can be varied between 10^{-4} and 10^{-8} A by selection of the appropriate grid resistor by means of the switch 6 (the minimum detectable photomultiplier current is 10^{-10}). This sensitivity is justifiable having regard to light-source stability, photomultiplier dark-current fluctuations and stray light level, though there would seem little to be gained by use of further amplification.

The remaining electronic apparatus used has been of fairly standard pattern, comprising stabilized 1 mA power-supply units of 3 and 5 kV respectively for the E.M.I. and the beryllium–copper photomultipliers.

OPERATION AND PERFORMANCE OF THE SPECTROPHOTOMETER

The mechanical features of the apparatus, some of which are of fair complexity, have proved reasonably satisfactory; a few possible improvements, suggested by experience with the arrangements as described, will be mentioned below.

As already explained, to protect the grating from corrosion likely to result in inexperienced hands from the passage of discharge products through the entrance slit (condition 7, p. 403), it was originally decided to use an expendable lithium-fluoride lens in front of the discharge tube, thus filling the grating aperture. This intention met with the difficulty that the polishing of crystalline lithium fluoride normally will result in a very great loss of transmission at the short-wavelength end of the Schumann ultra-violet range. After a number of trials, though use of the lens was satisfactory above about 1500 Å, the intention was abandoned, and the spectrometer was sealed off from the discharge tube by a cleaved plate of lithium fluoride, a few millimetres thick. The result of this step has been that, with the existing water-cooled hydrogen light-source described on p. 406, only about one-quarter of the grating aperture has been utilized. Nevertheless, with a 3 Å bandwidth and discharge-tube currents of 500 mA, very adequate signals, quoted below, have been obtained with both types of photomultiplier. Moreover, it has been found that, when using salicylated detectors, the lithium fluoride plate can be dispensed with altogether, the spectrometer then being in direct communication with the discharge tube and consequently filled with hydrogen at 1–2 mm pressure. The most immediate result of abolishing the lithium-fluoride window is to increase the range of the instrument to 900 Å as lower limit.

Representative signal and stray-light response data for several photomultipliers

		Signal (10⁻⁸ *A*				*u/s*		
Photomultiplier type	*No. of stages*	*Stray light*	1216 Å	1608 Å	2000 Å	1216 Å	1608 Å	2000
E.M.I. 6256 (quartz)	13	0·81	—	1900	330	—	2350	40
E.M.I. 6256 + salicylate	13	0·38	23	1500	60	60	4000	16
E.M.I. 9502 (glass) + salicylate	13	0·35	17	1200	48	49	3400	1
BeCu–Au, Allen type	11	<0·01	5·4	9	—	>540	>900	—
E.M.I. 6097 (glass) + salicylate	11	0·026	2·0	90	3·6	77	3500	14

From the foregoing explanation, and the data in the table to be discussed, it can be understood that the spectrometer described will perform well, with a spectral band width of 3 Å, when provided with a grating of one-half the linear dimensions of that employed here. This would represent a considerable economy. On the other hand, if and when it is desired to use a much narrower spectral band width, the unit construction of the present apparatus renders simple the embodiment of modifications in the slit assemblies and the anode end of the discharge tube, so as to increase the light-grasp by filling the existing grating. Thus, the forward end of the discharge capillary could be brought closer to the entrance slit (compare with Johnson *et al.*(8)), and the latter connected to the end portion 17 of the vacuum housing by a flexible metal bellows; in this way, the good degree of differential pumping needed to prevent the discharge from passing through the entrance slit could be maintained. A similar bellows connexion at the exit slit would probably be necessary if the beryllium–copper photomultiplier were used, because this would need to be pumped separately.

Such modifications, however, only concern use of the apparatus at narrower spectral band widths and in the region below 1200 Å. To date, condition 7 above has been an important requirement, and both the band width of 3 Å and the sensitivity realized with one-quarter of the grating surface filled, have been quite adequate. Accordingly, modifications of the above character have been avoided.

Wavelength calibration of the micrometer head 14 (Fig. 2), which is used for scanning the spectrum, has been performed by locating the heads of the bands of the CO Fourth Positive system and several lines of carbon and oxygen, which form the spectrum of the positive column discharge when used with carbon dioxide instead of hydrogen. As expected, within the accuracy limit of 3 Å, the results give a straight-line plot of micrometer reading against wavelength over the range 1200–2400 Å.

The graph of Fig. 7 represents typical results from a scan of the spectrum of the hydrogen positive-column tube, with a salicylated photomultiplier, type 6256 (by E.M.I. Ltd.); the discharge tube was here operated at 440 mA wit potential drop of 1·1 kV. As usual, the greatest intensit found in the hydrogen band structure near 1608 Å, and continuum which extends fairly free from lines from 165 through the quartz ultra-violet range, is weaker than 1608 Å peak by a factor of twenty-five. The ratio of intensity of the 1216 Å Lyman line to that of the 160 peak is lower than in the case reported by Johnson *et al* plainly because of the use of a lithium fluoride window h It is emphasized that Fig. 7 represents merely point-by-po readings over the spectrum, made for the purpose of ill trating sensitivity and intensity variations; no attempt been made to represent the resolution, which was, as stat approximately 3 Å.

The sensitivity and stray-light performance of the appara obtained with several different photomultiplier detectors shown in the representative data collected in the table. all cases, the water-cooled hydrogen discharge tube at a 500 mA was used, and a cleaved lithium-fluoride wind separated light-source and entrance slit.

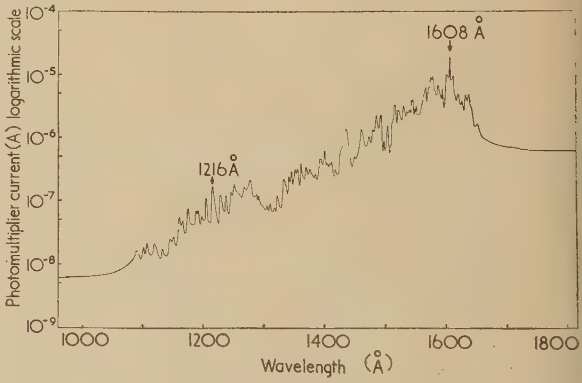

Fig. 7. Plot of spectrum of hydrogen positive-column discharge

The figures quoted for signal and for the ratio (*u/s*) useful to stray-light signals, are to be regarded only representing order of magnitude, because fairly wide var tions have been found between photomultipliers of a simil type and, according to the nature of the salicylate coatin the discharge conditions and the age of the lithium-fluori window. Thus, while the figures for 1608 Å and 2000 Å c be taken as fairly typical, the signal and *u/s* values for 1216 with a salicylated multiplier may vary by a factor betwe 0·5 and 2·0 from those listed.

The following points emerging from the data are worthy emphasis:

The stray-light baffling system, based on Pilkington bla glass, has plainly proved very efficient, as indicated by t high *u/s* values for 1608 Å. The absolute magnitudes of t signals obtained with the E.M.I. salicylated photomultiplie type 6256, justify the decision referred to above, that s lifications are unnecessary at present for the range above 0 Å.

second striking feature is the very good performance at 6 Å of the 11-stage Allen-type beryllium–copper photo-tiplier, with a gold cathode. This gives an absolute al some 2·5 times that of a salicylated glass photo-tiplier of the same number of stages (type 6097, by I.I. Ltd.), and certainly more than six times the *u/s* ratio. relatively superior performance (at least in signal, ugh uncertainly in *u/s*) of the type 6097 tube at 1608 Å, es to illustrate the discrimination shown by the beryllium–per multiplier against stray light.

n important factor in use of a beryllium–copper demount- photomultiplier is the age of the device in the practical se of the duration of exposure to air after activation of the odes. This was well illustrated by experience with a stage assembly. The photomultiplier, with a gold cathode, first tested within a day or two of its preparation, and e surprisingly high signal and *u/s* values. Thus, at 1216 Å signal was some five times that of the E.M.I. type 3256 cylated tube, and the *u/s* value was 2000; this, in spite of fact that, for lack of a power-pack of sufficiently high age, the dynode system was provided with 330 V per stage ead of the recommended 450 V. In the course of several ks' exposure to air, the signal obtained from this multiplier pped by a factor of ten, the *u/s* value remaining at about previous level, and the decline proceeded until the signal about one-twentieth of its original value. Whether or this sort of ageing effect can be avoided by storage of the otomultiplier assembly in a hard vacuum when not in use, nknown at present.

s remarked earlier, it has been found possible, using cylated detectors, to remove the lithium fluoride window n between the discharge tube and the entrance slit. In way, the region of useable signals has been extended n about 1130 Å to about 950 Å. The procedure is not, vever, very satisfactory. Thus, residual water vapour in hydrogen which now fills the spectrometer produces ong absorption bands in the region below 1300 Å, and it omes desirable to pass the hydrogen supply to the discharge ough a glass worm immersed in liquid air. Moreover, technique does not permit exploitation of an Allen-type detector. There is no doubt that the proper procedure for lowering the short-wavelength limit of the spectrometer is to modify the slit arrangements in the manner previously explained.

ACKNOWLEDGEMENTS

The authors take pleasure in thanking several members of the Atomic Energy Research Establishment for their co-operation, in particular, Mr. R. B. Owen and Mr. D. W. Smout for advice and actual construction of beryllium–copper photomultiplier assemblies, Dr. S. A. Ramsden and Dr. P. McWhirter for the loan of such devices, Mr. E. W. Pulsford for the design and construction of electronic gear, and Mr. K. R. Gamlen for the ingenuity in design of the detailed mechanism of the instrument. Thanks are due also to Mr. J. Yarwood of The Polytechnic, Regent Street, for arranging preliminary testing of the optical system, and to Messrs. Pilkington Bros., acting through Messrs. R. Earle and H. Kenny, for provision of excellent-quality polished black glass. The authors are grateful to Dr. H. M. Finniston and Prof. A. H. Cottrell for their encouragement during the making of this instrument.

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Laboratory and workshop notes

ick method of computing the transmission of zinc sulphide-magnesium fluoride multilayer filters

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use of two modified Smith charts provides a quick and y method for the determination of the normal transmission zinc sulphide-magnesium fluoride multilayers.

he Smith chart(1,2) is frequently used for calculating the smission of optical non-absorbing dielectric multilayers.(3) hough the method is fast, calculations for systems having ny layers are still laborious and mistakes are easily made. arge proportion of multilayer systems are composed of rnate layers of zinc sulphide and magnesium fluoride, and are designed to be used at normal incidence. It will be shown that a great improvement in the speed and ease of computation may be effected by redrawing the Smith chart to deal with these systems exclusively.

It will be observed that on the standard chart the impedance components are plotted in terms of a generalized characteristic impedance Z_0. It follows that when using the chart to obtain the transmission of a magnesium fluoride-zinc sulphide multilayer system it is necessary at each stage to carry out the operation of multiplying a complex number by $2 \cdot 30/1 \cdot 38$ or $1 \cdot 38/2 \cdot 30$ (normalizing). This operation is very tedious and a source of error in as much as complex numbers cannot be accurately plotted or read-off from the chart due to the highly non-linear nature of the co-ordinate network. These difficulties were alleviated by drawing two new charts for which the characteristic admittances had been given the explicit values of 2·30 and 1·38. Thus the "normalizing" operation was performed simply by transferring the complex number from one chart to the other without having recourse

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to any arithmetic. Since the two charts were drawn with an identical layout this operation could be performed rather more accurately and in less than half the time formerly required, also, as the complex number was merely transferred from one chart to another it was not necessary to record the intermediate results.

Example. To determine the transmission of the system:

glass — ZnS — MgF_2 ZnS — air

in which the thickness of the layers is such that $^{nd}/\lambda = 0 \cdot 10$ for the zinc sulphide layers and $^{n'd'}/\lambda = 0 \cdot 15$ for the magnesium fluoride layer. Take $n(\text{ZnS}) = 2 \cdot 30$, $n(\text{MgF}_2) = 1 \cdot 38$ and $n(\text{glass}) = 1 \cdot 52$. Using Leurgan's notation$^{(3)}$ the operational procedure is:

(*a*) Set cursor on the "zinc sulphide" chart at $1 \cdot 52 + j0$
(*b*) Advance arm by $0 \cdot 10$ on the wavelength scale so obtaining $Y_I = 1 \cdot 88 + j0 \cdot 75$
(*c*) Set up Y_I on the "magnesium fluoride" chart and advance arm by $0 \cdot 15$ to $Y_{II} = 1 \cdot 50 + j0 \cdot 80$
(*d*) Set up Y_{II} on the "zinc sulphide" chart and advance arm by $0 \cdot 10$ to $Y_{III} = 1 \cdot 28 + j0 \cdot 20$
then $k = Y_{III}/Y_4 = (1 \cdot 28 + j0 \cdot 20)/1 \cdot 0$.

To avoid having to compute the complex conjugate to obtain the reflectivity the radial arm of the "zinc sulphide" chart was provided with a "transmission scale", the spacing of which was such that the graduation line corresponding to a transmission $T\%$ was, for a chart 10 cm in radius, at a distance $\sqrt{(100 - T)}$ cm from the central pivot. To use the scale the value of k was multiplied by $2 \cdot 30$ and the number so obtained set up on the "zinc sulphide" chart. Thus in the example above one obtains $2 \cdot 94 + j0 \cdot 46$: which is found to lie under $97 \cdot 8\%$ on the transmission scale.

Remarks. This method of calculation takes no account of dispersion. It should be remembered that the effect of dispersion is small but for zinc sulphide in particular, is not negligible. The values of transmission obtained by this method will be most accurate in the region of 7500 Å, but in fact the values of the refractive indices are commonly taken to be constant at $2 \cdot 30$ and $1 \cdot 38$ whatever method of computation is employed.

ACKNOWLEDGEMENT

The author wishes to thank the Director and Council of the British Scientific Instrument Research Association for permission to publish this note.

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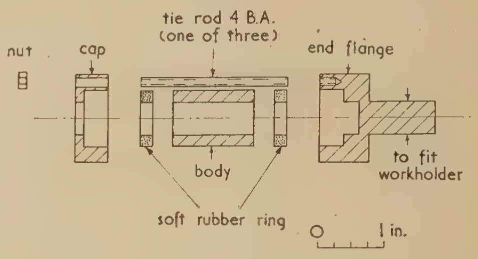
Rubber-jawed chuck for holding silicon crystals

By G. W. Green, Ministry of Supply, Royal Radar Establishment, Gt. Malvern, Worcs.

[*Note received* 29 *May*, 1959]

During the development of a floating zone machine for growing and refining silicon crystals it was decided to mount the seed crystal by grinding a taper at one end and fitting this with a corresponding taper at the end of the support rod. It is difficult to hold such crystals (which are grown from the melt by the Czochralski technique) during the grinding, because the variation of diameter along the length of, for example, a 1 cm diameter crystal is of the order $\pm\frac{1}{2}$ mm. Further, such crystals are not of truly circular cross-secti because of the vestigial crystal faces, while their brittlen presents an additional problem. The chuck to be describ meets these difficulties.

The design of the chuck (see figure) was suggested by vacuum pipe coupling used in the U.K.A.E.A.* In t chuck a rubber ring at each end of a tubular body is co pressed axially between the body and a flange so that only free to expand radially inwards, and will thus grip cylinder fitted into the assembly. It is clear that if the rin are uniform in thickness and hardness and are compress uniformly they will be extruded inwards uniformly. cylinder gripped by them will therefore be centred w respect to the axis of the assembly. This incidental prope of the coupling is an essential feature of the chuck.



Exploded view of rubber-jawed chuck

In this chuck the pressure is applied by three tie rods the sake of simplicity, and axial alinement of the object h is obtained by relative adjustment of three nuts. Howev it would be possible to make the chuck self-alining screwing the two ends on to the body. All parts are of br and are of circular section. Chucks have been made to co the range of crystal diameters between $\frac{3}{8}$ to 1 in.

For grinding tapers about $\frac{3}{4}$ in. long the seed crystal held so that about 1 in. protrudes from the chuck. It possible to grip crystals which are much smaller than t nominal bore of the chuck; there is no clearly defined low limit, but the crystal is held less rigidly as its diame decreases. Even so, it has been found to be practicable grind crystals whose diameter is 25% less than that of t chuck, and which have variations in diameter of this orc along the length. Provided the crystal is symmetrical abo its axis it need not be circular; for example, it is easy to ho square section bars, provided that the diagonal dimension near that of the chuck bore.

Grinding has been done using a workshop grindi machine fitted with a diamond wheel and a motor-driv rotating work holder into which the shank of the chuck w made to fit.

The principle used in this design may have application other problems in which it is necessary to hold and rota misshapen rods about their longitudinal axes.

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* Turnbull, A. H. *Vacuum*, **5**, p. 131 (1955).

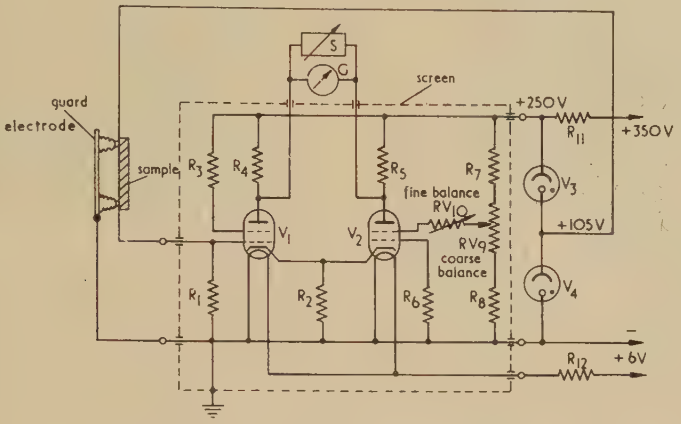
Simple d.c. amplifier for measuring very small currents

By G. Elliott, B.Sc., A.R.I.C., and J. A. Radley, M.Sc., F.R.I.C., F.S.D.C., Industrial Research and Development Laboratories, Reading, Berks.

[*Note received* 30 *April*, 1959]

The problem of measuring extremely small leakage curre in samples of insulating material was recently encountere as required to determine the insulation resistance of the ples with an applied direct potential of about 100 V. ne of the samples had insulation resistances of up to 10^{13} Ω and, therefore, currents of the order of 10^{-6} μA had to be measured. A review of the available s of galvanometer showed that the most sensitive instru- its had sensitivities of up to about 6000 mm deflexion/μA could therefore detect currents of about 10^{-4} μA. A nmercially available meter for high resistance measure- its covered the range up to a limit of 2 × 10^{13} Ω, but this itivity was only available when an applied potential of V was used.

ccordingly, a simple d.c. amplifier was constructed, so measurements could be made on a Cambridge galvano- er with a sensitivity of about 200 mm/μA. The simple uit shown in the figure was evolved after some experi- it, and was found to be quite satisfactory after a number sources of instability had been eliminated. The circuit sists of a "long-tailed pair" amplifier and is designed for asuring positive currents applied to the grid of V_1. The rent to be measured flows through the sample and the l resistor R_1, which is small in value compared with the nple resistance. The potential developed across R_1 causes anode of V_1 to swing negative and the anode of V_2 to ng positive, thus unbalancing the circuit. Initial balance obtained by varying the screen potential of V_2 by the stor train. If R_1 equals 100 MΩ, a sensitivity of about 10^{-6} μA/mm deflexion was obtained on the galvano- ter. The galvanometer was provided with an Ayrton shunt give higher current readings if required.



R_1 = 100 MΩ, h.s.
R_2 = 10 kΩ, h.s.
R_3 = 200 kΩ, h.s.
R_4 = 100 kΩ, h.s.
R_5 = 100 kΩ, h.s.
R_6 = 10 MΩ, h.s.
R_7 = 50 kΩ, h.s.
R_8 = 50 kΩ, h.s.
RV_9 = 100 kΩ, coarse balance
RV_{10} = 2·5 kΩ, fine balance
R_{11} = 10 kΩ, 5W
R_{12} = 2 Ω

V_1 = 6AM6 or 6064
V_2 = 6AM6 or 6064
V_3 = VR150/30
V_4 = VR105/30

G = Cambridge galvanometer (Sensitivity 200 mm/μA)
S = Ayrton shunt

Circuit for d.c. amplifier

he essential precautions to eliminate instability and zero ft are as follows:

a) All resistors should be of the high-stability type. The mal carbon variety change in value with time and are re sensitive to temperature. The potentiometers should rated at 2 W or higher, to avoid heating effects.

b) All supply voltages must be stabilized. Constant high tage was obtained by gas-filled voltage regulator valves, es VR105/30 and VR150/30 in series, as shown. The voltage for the insulation was also obtained from the 105/30. Stable heater voltage was obtained from a 6 V umulator, but a constant voltage transformer could also used. The heaters were run at a reduced voltage, using stor R_{12}, to help minimize grid emission.

c) The amplifier should be separate from the power supply a light-tight earthed box connected by screened cable. en such a delicately balanced circuit is being used, the valve electrodes are sufficiently photosensitive for considerable zero-shift to be caused by variations in ambient illumination.

(*d*) All insulation (of valveholders and terminals, for example) should be of P.T.F.E. or ceramic, to minimize leakage currents under humid conditions.

(*e*) The equipment should be switched on for one hour before use.

In the sample mounting, the usual precautions were taken, using an earthed guard electrode to bypass leakage currents in the mounting insulators. It has been pointed out that a commercially available instrument exists for measuring values up to 10^{14} Ω, employing the principle of measuring the time required to charge a standard capacitor connected to the input valve grid. However, in such a circuit it is not possible to arrange a satisfactory guard system and the connexion of the guard electrode to either the test voltage or to earth will result in an increase or a decrease, respectively, in the charging rate of the capacitor in the presence of leakage. For this reason, the charging circuit is not a suitable substitute for the measurement of d.c. leakage current.

This work was part of a larger sponsored research programme on electrical tapes, which will not be published *in toto*.

Stabilized d.c. supply suitable for energizing electromagnets

By D. C. Doughty, B.Sc.(Eng.), and D. G. Wenham, Grad.Inst.P., Research Laboratories, The General Electric Co. Ltd., Wembley, England

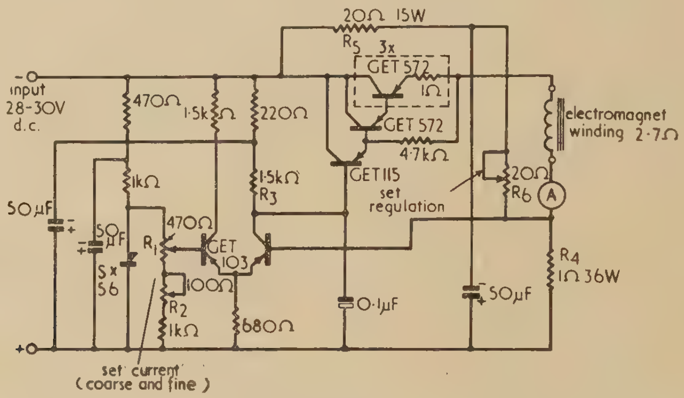
[*Note first received* 23 *February, and in final form* 8 *May,* 1959]

This note describes a simple current stabilizer using transistors which may be quickly constructed from readily available components. Important features are that no high-wattage variable resistors are required to control the current, and good stability is provided against supply fluctuations.

Although the circuit is of general application where fine control of the output current and good short-term stability are required, it has proved most useful in supplying direct current to a large laboratory electromagnet. The advantages of transistors are particularly apparent in this instance because of their high efficiency and ability to operate at low voltages and high currents, for which a valve design would have been impractical. As shown, the unit will supply from 4 to 6 A into a 3 Ω load and the current can be adjusted to within 1 mA. The unit was driven from a 3-phase, 50 c/s mains supply through a suitable transformer and rectifier system of conventional design. The circuit may be adapted to supply lower currents than 4 A by increasing the resistance R_4 in series with the electromagnet.

Three power transistors (for example G.E.C. Type 572) in parallel, mounted on a large cooling fin dissipating 15 W per transistor, are used as the series controlling element in a conventional constant-current stabilizer circuit. The voltage developed across the 1 Ω resistor (R_4) in series with the electromagnet coils is compared with a reference voltage developed across a Zener diode. Any difference is amplified and appears as a voltage change across R_3 which controls the series element. The two transistors (GET115 and GET572) are interposed between the voltage amplifier and the series transistors to provide a high current gain in the circuit. Coarse and fine current control is obtained by variation of R_1 and R_2. The resistance network R_5, R_6 provides, in addition, a voltage directly proportional to unstabilized input. By this feed-forward technique a us degree of additional stabilization against input vol fluctuations can be obtained, although the setting of R slightly affected when the magnet current is altered.

The following performance figures were measured a load current of 4·5 A and an ambient temperature of 24 after the magnet and power supply had reached a ste temperature.



Constant-current stabilized power supply for electromagnet (4–6 A)

(1) With the input voltage constant, the load curren not drift by more than 1 part in 2000 over a p of 20 min.

(2) With R_5 open-circuit, the load current change 60 mA (1·3%) for a 10% change in input voltage

(3) With R_5 reconnected, it was possible to improve degree of stabilization by a factor of 10 (that is 0·13%). There was no observable change in degree of stabilization over a period of 30 min.

NOTES AND NEWS

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impro products. The Institute of Physics assumes no responsibility for the statements given below: information for these has b taken from literature supplied.

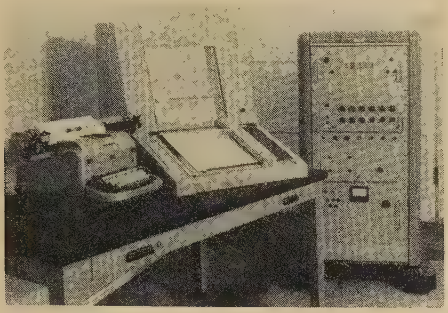
Labjack. J. H. Towers and Co. Ltd., Victoria House, Widnes, Lancashire.

This device is based on the screw principle and is intended, among other uses for operations necessitating the careful raising or lowering of equipment such as water baths, oil baths, heaters, etc.; supporting Dewar flasks when used for cooling traps in vacuum systems; supporting flasks, etc., which must be readily removable, as in assemblies of interchangeable ground joint glassware.

The 8 in. square top and bottom plates are removable and from a minimum height of 3¼ in. the Labjack will extend to 11¼ in. giving a maximum lift of 8 in. It is claimed to lift up to 20 lb. from zero height, but when slightly extended will lift 56 lb. It is soundly constructed of anodised light alloy and provided with a large bakelite knob which operates the raising and lowering of the top platform, giving a precise control.

Trace reading equipment. Southern Instruments Compu Division, Frimley Road, Camberley, Surrey.

This equipment is intended for reading oscillograph traces film or paper up to 12 in. width. Linear or non-linear ca brations may be introduced by means of calibration cur drawn on ordinary graph paper. The output can be re-plot in graphical form or digitized and displayed visually, tab lated by means of an electric typewriter or punched on car or tape. The trace reader takes the form of a desk-shap console, on the sloping top of which, immediately in fr of the operator, is displayed the calibration chart consisti of a curve drawn on ordinary 10 × 12 in. graph paper. J behind and above the calibration curve is the record carri The record is placed on a spool at the top of the carrier a passes down over the front face, where a length of about 12 is in full view of the operator. It then passes round a h al drum just behind the rear edge of the calibration chart is re-wound on a second spool. Two reading cursors provided, both operated by a single handle controlled he right hand of the operator. The first cursor travels zontally across the record and is positioned on the trace left-to-right movement of the hand. The second cursor ws this movement across the calibration chart, and is positioned vertically to coincide with the calibration e. In this way, the horizontal deflexion of the recorded is translated into a vertical movement proportional to calibrated reading. This movement in turn is then con- d into a voltage by means of a linear potentiometer, the r of which follows the vertical movement of the cursor. nob conveniently placed to the left of the operator rols the positioning of the record, which is wound on veen readings to bring successive timing marks to a l index line. A further knob adjusts the record sideways ring the zero or datum line into alinement with a second x line. It is also possible to obtain a reading proportional listance along the record from a potentiometer coupled he lower drum. When the cursors have been moved position depression of a print-out bar brings into action digitizer, which converts the output voltage into digital 1, displays it visually as illuminated figures and also es it to the electric typewriter or punch. The required tizer scale is selected by means of a switch which can be nged to select the correct scaling factor for any number hannels up to 12 in any pre-arranged order and to indicate neans of lamps which channel should next be read.



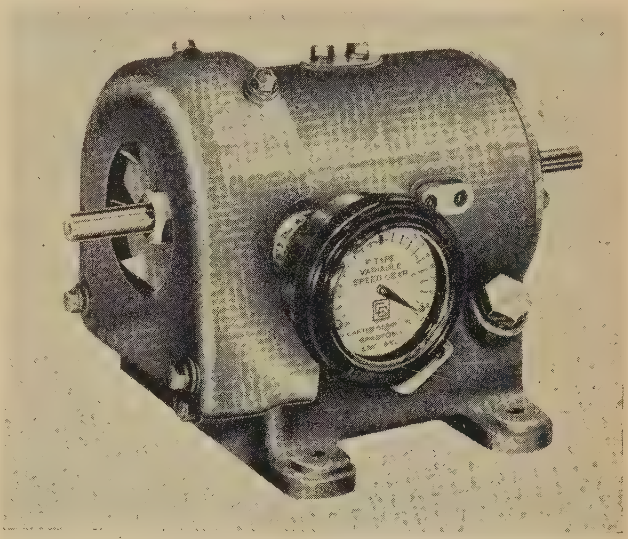
ulti-channel trace reading equipment with programme unit and separate calibration for each channel

velling-wave-tube amplifiers. Marconi Instruments Ltd., St. Albans, Herts.

new travelling-wave-tube amplifiers are now available. e TF 1278 covers the L-band (1200–1400 Mc/s) and type 1278/1 covers the S-band (2700–3500 Mc/s). The two plifiers are claimed to have noise figures of 8 and 7 dB ectively. Both have a gain variable up to at least 20 dB a maximum power output of 1 mW. High-speed rnal pulse and phase modulation can be applied, so that instruments can be used as modulator stages in micro- e systems. To allow gain adjustment and maximum bility in setting up, the helix and individual grid voltages controllable from the front panel. Any of these voltages be displayed on the multirange panel meter, which can be switched to monitor helix and collector currents. ernal gain control and monitoring may also be employed. e C coaxial connectors are used for the r.f. input and out.

Infinitely-variable speed gears. Carter Gears Ltd., Bradford 3, Yorks.

Hydraulic variable speed gears, giving infinitely variable output speeds from a constant input speed, are available from this firm. Output speed may be controlled by either handwheel, remote electrical or lever arrangements and with the gear either running or stationary. One of the alternative handwheel controls, the combined handwheel and speed indicator, is illustrated. Approximately 8½ turns of the handwheel are required with this type of Carter gear to cover the full speed range from maximum forward, through zero to maximum in reverse. The output speed/control movement relationship is approximately linear so that from any position equal control movements result in equal speed changes in r.p.m. The size of the variable speed gear is about 8 × 8 × 12 in. for the smallest of ten sizes.



Variable speed gear showing the combined handwheel and speed indicator.

Radiation dosemeter. Radiatron, 7 Sheen Park, Richmond, Surrey.

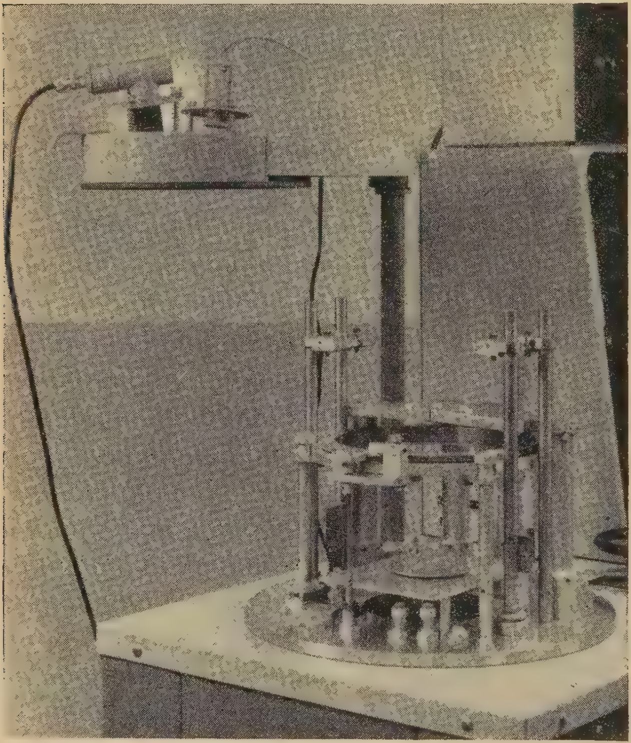
The Condiognom dosemeter has twin condenser chambers which are screwed together to form a very light unit of the approximate size of a fountain pen. They are provided with a clip and are not separated except when measuring. Each chamber is hermetically sealed and operates independently. The measuring range of the larger chamber is 0–100 mr, and thus adequately covers the maximum permissible daily dose for personnel engaged in radioactive work. The measuring range of the smaller chamber is 0–1000 mr, and this chamber is designed to register any quantities received when the larger chamber is completely discharged. The walls of the chambers are transparent to radiation and the centre electrodes are amber-insulated. The chambers are charged separately before being issued to personnel. Ionizing radiation partially discharges each chamber and the loss of charge is determined by measuring the chamber voltage electrostatically. The meter indicates the dose directly in milliröntgens. Air wall materials are used in the chambers, and the readings are therefore independent of radiation energy from 50 keV to γ-rays of cobalt and radium.

Self-setting surveyor's level. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

The Autoset level incorporates an optical device which automatically levels the line of sight. In using the level, it is merely necessary to centre a circular bubble on the tribrach to within 20′; the automatic stabilizer then levels the line of collimation for every sighting. The stabilizer unit, inserted between the objective and eyepiece, consists of a fixed roof prism between two suspended prisms. The latter are supported by four metallic tapes forming a cross-spring flexure pivot. The pendulous double prism changes its angular relation to the optic axis at the same rate as the telescope is tilted, so that a horizontal beam of light passing through the objective remains focused on the cross-wires. Oscillation of the suspended prisms is damped by an air-damping piston, which also restricts the total swing to ±20′ and takes the weight of the prism mount when the level is in transit. A re-levelling accuracy of 1″ is claimed for the stabilizer.

Optical vacuum coating plant. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.

The work chamber of the type 12E7 plant consists of a hard glass bell jar, 12 in. in diameter and 14 in. high, sealed to the vacuum base plate by an L-shaped rubber gasket. The work is supported on a ring in a ball-bearing drive contained on a removable metal frame attached to the vacuum base-plate (see figure). This work-holder is driven through a rotary vacuum seal by a 1/12 h.p. motor with a reduction gear. Two pairs of electrodes are fitted for evaporation purposes. Four special electrodes for the sector cathodes are also incorporated in the vacuum base-plate, in addition to two electrodes for ionic bombardment cleaning if requir The plate on which the photometer is mounted rests on of the metal chamber guard and carries the photocell light source for reflexion measurement. For transmiss measurement, the light source is transferred to the cham base-plate.



Base-plate assembly of optical film, vacuum coating plant. The filament source and cathode plates are arranged for downward deposition

The pumping system consists of a 4 in. oil diffusion pu having a baffled speed of approximately 200 l./s. This backed by a single-stage rotary pump with a displacement 5 ft^3/min. The pumping system is complete with suita pipework and manually-operated valves for backing a bypass. Air admission to the chamber and rotary pump effected by type RS1A valves, and fine control of air admissi for ionic bombardment and sputtering is obtained by a ty OS1C needle valve. Vacuum measurement in both chamber and the roughing system is provided by a combir Pirani/Penning vacuum gauge, the cold-cathode ionizati head of the latter being screwed directly into the vacuu base-plate. A vacuum switch provides protection by au matically isolating the electrical supply when the w chamber is at atmospheric pressure, and a thermo-swit on the diffusion pump cooling coils protects the pump fr overheating, should the water supply fail.

High- and low-tension supplies are provided, the for by a transformer having an output of 250 mA at 3 kV. output from this transformer is fed to the chamber sputte or cleaning electrodes *via* a changeover switch operated fr the instrument panel. Power for the l.t. supply is through transformer rated at 150 A at 10 V continuous or 20 intermittent.

High-sensitivity cathode-ray tube. Mullard Ltd., Torringt Place, London, W.C.1.

The type DH10-78 tube has a 4 in. diameter flat screen and overall length of only 12 in. It uses electrostatic focusi and deflexion and is suitable for double symmetrical oper tion. The post-deflexion accelerator consists of a hig resistance coating applied in the form of a helix to the insi of the bulb. This helical electrode provides a continuo gradient of acceleration voltage, resulting in smaller patte distortion, so that higher post deflexion acceleration ratio to 4:1 may be used. Pre-deflexion acceleration may therefc be kept low so as to obtain high sensitivity, and the fir accelerating voltage can be high to obtain maximum brig ness. It is stated that under typical operating conditio X and Y sensitivities of 30 and 10 V/cm respectively can achieved with a post acceleration voltage of 4 kV. additional feature of the tube is that the shield between t two pairs of deflexion plates is brought out separately, that the shield voltage may be adjusted to correct pin-cushi or barrel distortion. The screen of the tube uses a phosph with blue and yellow components giving, under norm excitation conditions, a greenish fluorescence of mediu persistence.

Daylight integrating meter. Photoelectronics (M.O.M.) Lt Oldfields Trading Estate, Oldfields Road, Sutton, Surr

This unit comprises a photocell and special transist amplifier which drives a low-inertia, integrating counti meter. When maximum daylight falls on the photocell t meter records a maximum count of one division in 55 the rate of count being directly proportional to the daylig intensity. The total count before automatic reset is 10 0C The photocell is housed in a 2½ in. diameter, cast aluminiu therproof case, and the distance between the cell and trol unit can be up to 100 ft. The control unit is a pressed l housing with hinged lid suitable for wall mounting. It tains the integrating meter, transistor amplifier and ver supplies.

velling-wave tube. Mullard Ltd., Torrington Place,
London, W.C.1.

type LA9-3 is a broad-band, travelling-wave tube intended use as a signal amplifier in the frequency range 7000 to 00 Mc/s. It is stated to provide a power gain of 27 dB r this range without adjustment, and to have a saturated ver output of 6 mW. The tube may be focused by a noid taking 5 A at 25 V or, more compactly, by a periodic nanent magnet system. The noise factor is 18 dB with noid focusing and 23 dB with permanent magnet focusing. type LA9-3 may be used to increase the sensitivity of ad-band receivers operating in the X-band, as a general-pose laboratory amplifier or as a crystal protecting device. nount incorporating a permanent magnet focusing system a waveguide output is available.

cational model servo-mechanism. Evershed and Vignoles
Ltd., Acton Lane Works, London, W.4.

s equipment is designed to demonstrate the action of rse types and arrangements of servo-mechanisms. It sists of a servo-unit and a duplex quick-response recorder n separate amplifier. The servo-unit incorporates a ver pack, a d.c. amplifier with phase-sensitive rectifier and h-pull output stage, and a d.c. split-field motor generator. ocity feedback, adjustable by a potentiometer, is generated nin the unit and may be converted to acceleration feedback an auxiliary capacitor. There are also facilities to provide external phase advance. A precision gearbox is attached the servo-motor, the shaft of which is extended so that tia loads may be added to the system. All parts of the o-unit are arranged on a baseboard and interconnected multi-plugs so that each part may be withdrawn separately. he quick-response recorder is of the continuous-roll chart e and contains two d.c. recording voltmeters. It is stated provide a rapid response with negligible pen friction. recorder operates in conjunction with a separate amplifier which it is connected by multi-core cables and plugs.

curately-controlled pulse generator. Sunvic Controls Ltd.,
Harlow, Essex.

hough designed primarily for accurate measurement of se height analyser channel threshold, and width, it is med that this instrument is suitable for many other lications in which a shaped pulse of stable and accurately own amplitude is required.

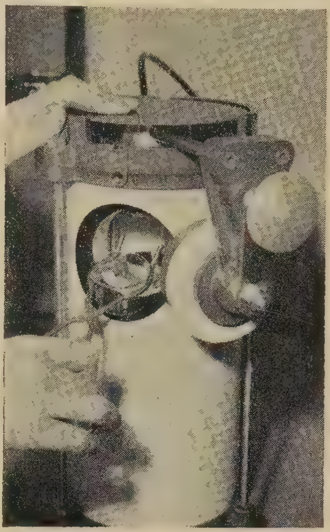
he instrument consists of three main sections; stabilized ver supply, voltage divider network and pulse-forming work. The pulse amplitude is adjustable over the range 0 V by the main control, and there is also an incremental trol which provides continuous variation over a range of -1·24 V with a linear accuracy of ±2 mV.

he overall amplitude stability tested during an eight-hour iod is stated to be better than ±0·025% (allowing for a ins variation of 5%).

three-position switch selects pulses of widths 1, 5 or us; the pulse polarity may be either positive or negative, l at a repetition rate equal to the mains frequency. The nensions of the instrument are approximately 11 in. h × 19 in. wide × 10 in.

High-efficiency scintillation counter. Panax Equipment Ltd.,
Holmethorpe Industrial Estate, Redhill, Surrey.

This instrument has been developed for the counting of millimicrocurie quantities of very low-energy β-radiation emitters such as tritium and carbon 14. The counter is intended primarily for use with liquid phosphors, but can also be converted for use with plastic phosphors and sodium iodide crystals. The equipment consists of a 1·5 in. thick lead-walled container, fitted with a light-tight door (see figure), which is interlocked with an e.h.t. switch and a shutter assembly to protect the photomultiplier, and to prevent external light increasing the background count.



A liquid sample being inserted for scintillation counting

Normally a standard 30 ml. glass jar is used to hold the liquid phosphor, into which the radioactive source to be counted is placed. Since the shutter closes automatically, when the container door is opened, and operates a micro-switch, samples can be changed in normal room lighting while maintaining a low level of background counts. When in position in the container, the bottom surface of the glass jar is adjacent to the sensitive surface of the photomultiplier tube, and good optical contact is maintained by means of a liquid light guide. The shutter assembly can be replaced by a crystal mount which will accept 1·5 in. diameter by 1 in. long sodium iodide crystals or plastic phosphors of similar dimensions. By inverting the unit, liquid and solid samples can be investigated with minimum air gap between sample and detector. The high efficiency counting of low-energy β-emitters in other forms can also be carried out with this equipment.

For counting purposes, the counter is used in conjunction with a linear amplifier and suitable scaling apparatus incorporating discriminator and e.h.t. supplies. It is claimed that efficiencies of 10% for tritium, and 50% for carbon 14 have been obtained at room temperature, but higher efficiencies can be obtained by cooling the container in a standard refrigerator.

Servoscope for the analysis of servo-systems. Servo Corporation of America, New Hyde Park, Long Island,
New York, U.S.A.

This instrument is designed to measure phase, transient response and gain; and, it is claimed, is of use in accurate plotting of Nyquist, Bode or Nichols diagrams. It generates sine waves and modulated carrier wave-forms, and covers the frequency ranges 0·1–2·0 c/s and 1·0–20 c/s. It gives a direct reading of both amplitude and frequency, and a direct read-out of the phase lag. The frequency accuracy is ±5% of the setting. The size of the instrument is 19 × 9 × 12 in. approximately.

Cobalt platinum magnetic alloy. Johnson Matthey and Co. Ltd., 73–83 Hatton Garden, London, E.C.1.

The outstanding magnetic properties of certain alloys in the cobalt platinum series have been known to metallurgists for many years, but it is only recently that the properties of the alloy containing equal numbers of the atoms of each element (23·3% by weight of cobalt) have been fully appreciated. The alloy described here is the latest development in this field.

After heat treatment by a special process, the makers claim that it has remarkable physical and magnetic properties; a remanence of about 6400 G, a coercive force of 4800 oersted, and a BH (max) of $9 \cdot 2 \times 10^6$ G oersted being obtainable. Moreover, in the heat-treated state the alloy is magnetically isotropic, exhibiting similar magnetic properties in all planes.

Apart from the benefit of its magnetic properties, its use offers further advantages in that it is comparatively workable before heat treatment, and can be machined, rolled and drawn without difficulty. It thus lends itself to the manufacture of magnets of complicated shape or extremely small size.

Swept-frequency signal generator with visual display. Aveley Electric Ltd., Ayron Road, Aveley Industrial Estate, South Ockendon, Essex.

The Polyskop, manufactured by the German firm of Rohde and Schwarz, consists of a frequency-modulated signal generator with a two-channel display unit and a large-screen television display tube. The signal generator itself has five frequency ranges from 0·5 to 400 Mc/s; adjacent ranges overlap at least 10 Mc/s. The centre of the frequency sweep is adjustable to any point within the ranges, and the sweep width is adjustable (within the limits of the frequency ranges) from ±0·2 to ±50 Mc/s. The frequency modulation is sinusoidal at mains frequency, and the oscillator is switched off during the return sweep so as to provide a zero reference line on the display tube screen. The display section of the instrument contains two identical video amplifiers with an electronic switch so that two quantities (e.g. the input and output signals of a 4-terminal network) can be simultaneously displayed. Diode probes to suit various input impedances are provided. Frequency markers at 1, 10 and 50 Mc/s, independent of the main signal generator, are provided for the accurate adjustment of the swept frequency range. Provision is made for audio-frequency amplitude modulat
from an external source and also for the injection o
frequency marker of any frequency from external apparat

Potentiometers with servo-mountings. P. X. Fox, L
Hawksworth Road, Horsforth, Yorks.

The potentiometers with servo-mountings of a design us
high precision windings, are housed in a special al
aluminium case to ensure a high rate of heat dissipat
while giving a low torque characteristic.

They are of outside diameter 1·19 to 2·53 in. and h
resistances up to 100 kΩ. The potentiometers may be gan
together, and the torque varies with the number of gan
units, but ranges from 0·5 g cm.

They can be used in many types of electronic industr
and scientific equipment, including computers.

Transistor d.c. voltmeter. Soundrite Ltd., 82 New Bo
Street, London, W.1.

The model 140 d.c. voltmeter manufactured by Amos
Exeter has six basic voltage ranges, five of which can
extended by a ÷ 2 push-button. The voltage range cove
is from 0·5 V to 20 kV, and the input resistance varies fr
150 kΩ on the lowest range to 200 MΩ on the 5, 10 and 2
ranges. The instrument is calibrated against an inter
reference voltage stated to be accurate to 1%; the stabi
of the calibration is better than 1% over a period of t
hours, and there is no zero drift. The instrument is au
matically protected against overload. A centre-zero fa
is provided so that the instrument can be used as a sens
galvanometer.

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NOTES AND NEWS

Notes and comments

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ORIGINAL CONTRIBUTIONS

High intensity, high speed, multiflash apparatus

y G. Dixon-Lewis, M.A., D.Phil., and E. G. Jackson, B.Sc., Ph.D., The Houldsworth School of Applied Science, University of Leeds

[*Paper first received* 30 *April, and in final form* 20 *July*, 1959]

An apparatus has been constructed to provide a number of high-intensity xenon flash discharges at time intervals from $0{\cdot}1$ to $2{\cdot}5 \times 10^{-4}$ s between flashes, each flash dissipating 300 W.s in approximately 180 ms. Two flash-head arrangements were used: in one, the tubes were mounted on a rotating disk thus giving a series of flashes from one fixed position, whilst the other consisted of a stationary bank of tubes, the location of the individual tubes determining the position of each flash.

bserve flow patterns in gas streams, small particles of esium oxide are frequently added to the gas, and the cle tracks are recorded photographically.(1–4) To deter- flow velocities, it is necessary to illuminate the particles intermittent light source of known frequency. A high- sity light source is required if particles less than 10 μ ameter are to be photographed. A single electronic flash fired repetitively can only dissipate approximately 4 W.s lash because of the great energy requirements at high ing rates. Higher light outputs are obtained by using a of flash tubes, each associated with its own storage citor. The apparatus described uses eight flash tubes, idually capable of dissipating 300 W.s per flash. Two of flash-head arrangements have been used; in one the tubes were attached to a rotating disk whilst in the the tubes were stationary.

POWER SUPPLY

e energy required for each tube was stored in a 100 μF nol photo-flash capacitor (by T.C.C.) charged to a ntial of 2·5 kV, the potential applied being indicated by lectrostatic voltmeter. The main power pack used for ging the capacitors supplied 150 mA at 2·8 kV, d.c. A nd power pack provided a 4 kV smoothed d.c. supply h was used to trigger the tubes. Some reservoir capaci- e was incorporated in this latter supply to ensure reliable g at the higher speeds. The eight capacitors were con- d in parallel to the 2·8 kV supply for charging, and isolated when they had attained a potential of 2·5 kV. 8-pole high-voltage switch was constructed for this ose. The trigger potential was switched to the firing actor by means of a high-voltage Londex relay. The ive terminals of both power packs were connected to a mon earth to overcome the effects of the positive wall ge acquired by the tubes after firing. A leak resistance d be switched across the capacitors to discharge them ld a tube fail to fire.

ROTATING FLASH HEAD

photograph of this flash head is shown in Fig. 1. The tubes, type Fa4 (by The British Thomson-Houston Ltd.), were of circular form, having two power leads ss which the working potential of 2·5 kV was applied, a trigger electrode consisting of a band of conducting on the tube surface (Fig. 2). Each tube was fitted into shaped polished-aluminium reflector which had a slot cut e back to accommodate the electrical leads. The tubes and reflectors were mounted radially, at 9 deg. intervals, between two 14 in. diameter Tufnol disks. The edges of the reflectors fitted into slots milled in the inner faces of the disks. The Tufnol disks were mounted on a $\frac{1}{2}$ in. diameter steel axle running in self-alining bearings, the whole being driven through a flexible coupling by a variable-speed motor. The rotating assembly was carefully balanced to minimize vibration and the periphery of the disks was enclosed by

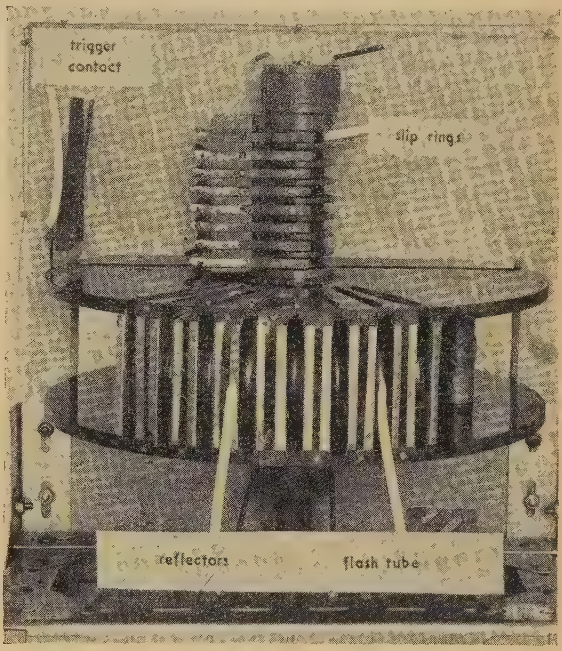

Fig. 1. Photograph of rotating flash head

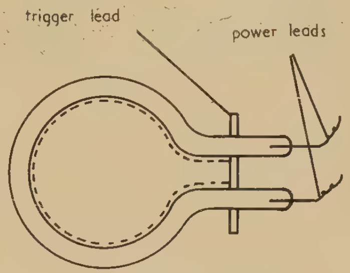

Fig. 2. Flash tube

transparent plastic sheet to reduce wind resistance. Mounted upon the upper face of the top disk were 8 slip rings, connected individually to one power lead of each tube. The other power lead from each tube was connected to a common slip ring below the lower disk. Above each tube on the upper edge of the disk was a small stud, connected to the trigger lead of that tube. A single stationary contact was placed adjacent to the periphery of the top disk so that, when the disk was rotated, the clearance between the moving and fixed contacts was approximately 0·002 in. Initially, power was supplied to the slip rings through bronze strips, but the large currents during firing caused severe arcing, and consequent pitting of the copper rings. This was rectified by bolting copper–carbon blocks to the strips, the blocks being shaped to give a large contact area with the slip ring. Each reflector was connected to the common earth via a 1 MΩ resistor, which was found to prevent two tubes firing simultaneously.

STATIC FLASH HEAD

The flash tubes were mounted in U-shaped reflectors as before, the reflectors being arranged in an arc with their open ends towards the centre. Because the flash tubes were stationary, their power leads were permanently connected, and the only moving contact was that required to switch the trigger potential to the tubes. This was achieved by having eight static contacts swept by a charged wire mounted on a Tufnol disk (Fig. 3). The disk was 12 in. in diameter and had a copper slip ring attached to one face. A length of copper wire ran radially from this ring to the periphery of the disk. The trigger potential was fed to the slip ring by a spring-loaded carbon brush. The eight static contacts consisted of small studs screwed into a Tufnol block at 4 deg. intervals on a 6 in. radius circle. The ends of the studs facing the disk were turned to a sharp point, the gap between the studs and the wire being approximately 0·002 in. It was found necessary to connect these studs to the trigger contacts on the tubes with co-axial cable, the screening being earthed. Each reflector was linked to earth via a 1 MΩ resistor as in the rotating flash head. These precautions prevented the inductive firing of more than one tube when the trigger potential was applied.

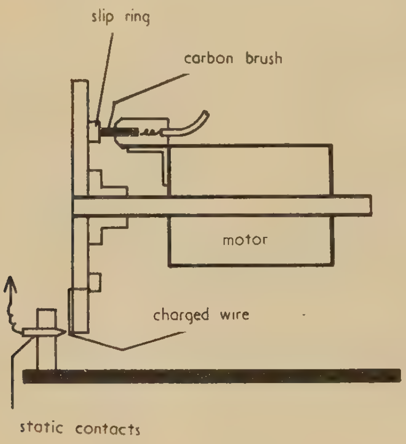

Fig. 3. Trigger switch

FIRING PROCEDURE

Rotating head. The capacitors were charged to a pote of 2·5 kV by the main power pack before being isolated. disk was rotated up to the required speed and the supply switched to the trigger contact. Each tube then when it reached a position adjacent to this charged con The disk was not rotated while the capacitors were b charged because a premature firing could cause the capacitance of the apparatus (800 μF) to be discha simultaneously.

Static head. The firing sequence for this flash head similar to that used for the rotating head, the capac being charged and isolated before the triggering device rotated. The residual potential remaining in the capac after firing was dissipated by switching the leak resist across them. The wall charge acquired by the tubes be allowed to leak away before another run is attempt premature firing is to be avoided.

PERFORMANCE

Both flash-head arrangements have been used success for illuminating small particles of magnesium oxide entra in gas streams. The static flash head was simpler to const but the position of the flashes depended on the placi the tubes. The use of a 3000 rev/min motor gave flashes at intervals of $2{\cdot}2 \times 10^{-4}$ s, lower flashing rates obtained by operating the motor at slower speeds. rotating flash head, although more complex, yielded fla from a fixed spatial position. This system gave a seri flashes at intervals ranging from $0{\cdot}1$ to 1×10^{-3} s, the ing factors being the tube spacings and the maximum rotational speed of the disk.

The number of flashes obtainable depends upon the nu of flash tubes and capacitors used; a maximum of 40 c be used in the rotating head described. The maxi number of tubes in the static flash-head system is determ by the number of contacts round the trigger switch. Gr light outputs per tube are possible by the use of la capacitors but this leads to a reduction in tube life.

ACKNOWLEDGEMENTS

The authors are indebted to the Joint Research Comm of the Gas Council and the University of Leeds for permis to publish this paper, and to Dr. G. L. Isles and Dr. J Kilham of this department, and Dr. P. L. Marsden of Physics Department, for helpful discussions during construction of the apparatus.

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Neutron diffraction instruments at a high-flux nuclear reactor

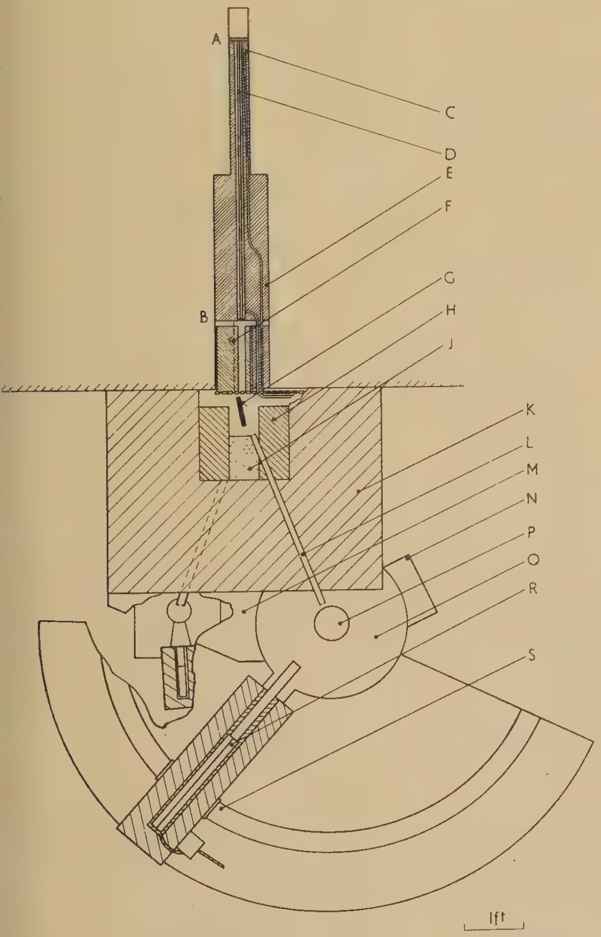
G. E. Bacon, M.A., Ph.D., F.Inst.P., and R. F. Dyer, Atomic Energy Research Establishment, Harwell, Berks.

[*Paper first received* 15 *June, and in final form* 30 *June*, 1959]

A description is given of an assembly at a high-flux reactor of two instruments for neutron diffraction measurements. One is a large instrument for use with polycrystalline samples: the other, much smaller, is for single-crystal work. An account is included of the associated in-pile equipment and shielding for producing the collimated beams of thermal neutrons.

INTRODUCTION

ure developments in the application of neutron diffraction end very much on the use of high-flux reactors. Most he work carried out during the past 10 years has been at graphite moderated reactors, using natural uranium uel and giving a thermal neutron flux of about 2 × 10^{12} rons cm^{-2} s^{-1}. In the last two or three years a number esearch reactors giving much higher fluxes, of about 10^{13}, have been commissioned and the increased intensity he neutron beams which they offer is very attractive. reactors employ enriched uranium as fuel and the size he core is very much less than for the earlier reactors. he case of the Harwell heavy-water-moderated reactor DIDO the core is only two feet in height, with the result that the number of experimental holes which can be included is very limited. Some of the horizontal holes are closely spaced in pairs with their centre lines two feet apart vertically. We describe an assembly of two neutron diffraction spectrometers, designed to work at such a pair of holes. The upper instrument is a large "powder spectrometer" and the lower one is a small instrument for studying single crystals and the designs are conditioned by the need to accommodate both within the limited vertical distance which is available. Because of the high costs of operating reactors it is, of course, essential to utilize fully all the holes provided, quite apart from the advantages of having two instruments available.



ig. 1. Diagrammatic layout of the two spectrometers t the reactor face. The counter track of the upper nstrument is shown cut away to reveal the single crystal nstrument at the lower hole. The components indicated by the letters *A*, *B*, etc., are referred to in the text

Fig. 1 shows, in diagram form, a plan of the experimental layout of the two instruments at the reactor face. The figure includes the collimators and monochromating crystals, with their surrounding biological shields, together with the rotating counters and sample tables which form the basis of the systems for measuring and recording the diffraction patterns. Fig. 2 is an artist's sketch which makes clearer some of the details, particularly the relative positioning of the two instruments in the vertical plane.

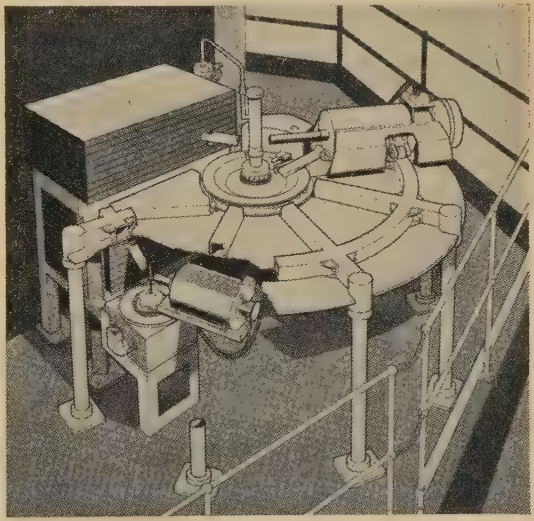


Fig. 2. An artist's sketch of the two instruments showing, in particular, their relative vertical positions

NEUTRON COLLIMATORS

In designing the collimators it is essential to arrange that the radiation near the reactor face can be brought down to a safe level under all conditions, so that, for example, adjustment can be made to the shielding and the monochromator while the reactor is running at full power. Each of the two reactor holes is fitted with a collimating tube (*AB* in Fig. 1) which provides a stainless steel lined channel, 5 ft long, from which the neutron beam emerges. The upper hole has an aperture *B* which is $1\frac{1}{8}$ in. in width and $1\frac{1}{2}$ in. high, opening out to 2 in. at the "in-pile" end *A*. The width of $1\frac{1}{8}$ in. is divided into three separate channels of $\frac{3}{8}$ in. width by two vertical steel slats *D*, thus limiting the horizontal angular divergence to about $\frac{1}{2}°$ but permitting a large sample to be irradiated by the neutron beam if necessary. On the other hand the collimator serving the lower, single crystal, instrument has a much smaller aperture of $\frac{1}{2} \times \frac{1}{4}$ in., opening to $1\frac{1}{4} \times 1$ in. at the inner end, which is quite large enough for irradiating single crystals. The two ends *A*, *B* of the collimators are sealed with 0·010 in. stainless steel diaphragms which cause little absorption of the entering and emerging neutron beams. In each case stainless steel pipes, shown at *C* in the figure, are welded to the collimating tube to permit flooding the tube with water, and subsequent draining. This provision is made to provide a fast-neutron shield when adjustments are being made at the reactor face. The collimating assembly is finally welded into a steel casing, which is machined to fit the reactor hole, and the space between case and collimator is filled with iron-shot concrete, *E*.

Immediately in front of the collimator, just within the reactor face, is positioned a lead-filled plug *F* which serves as a stopper for the γ-beam from the reactor core. When the reactor is running at full power there is a γ-flux near the monochromating crystal *G* of the order of 10^6 mr/h, which requires about 15 in. of lead to reduce it to a biologically safe level. Within the lead plug is an eccentrically mounted steel shell in Teflon bearings, which is lead-filled except for a cadmium lined hole with the same dimensions as the aperture of the collimator. Rotation of this inner plug by 180° opens the aperture and permits the exit of the neutron beam from the collimator.

The entire assembly is sealed into the reactor by O-ring gas seals and then purged with CO_2 to exclude air. This procedure avoids corrosion effects which would arise from the production of nitric acid by irradiation of atmospheric nitrogen in the presence of water vapour and also prevents any production of argon 41 which is a health hazard. Great care has to be taken to ensure that sealing is complete, bearing in mind that there are many possible leakage paths for gas, for example around the water pipes and the bearings of the rotating plug. The water which is used for flooding the collimating tube is de-mineralized and de-aerated and kept under a blanket of helium, again to prevent entry of atmospheric nitrogen into the system.

MONOCHROMATOR AND SHIELDING

Each neutron beam impinges on a monochromator *G* which is a single crystal of lead or copper mounted in the reflexion position on a standard set of goniometer arcs. These are carried on a rotatable table which is fixed to the supporting frame on the reactor face. The controls for rotating the table and adjusting the goniometer, together with the controls for the water circuit and lead plug, are brought to a point on the reactor face outside the shielding *K*.

Only about 1% of the neutrons in the incident beam from the collimator are reflected by the monochromator and used in the subsequent measurement of diffraction patterns. The remainder of the beam from the reactor has to be absorbed in shielding placed around the monochromator, in order to make the radiation level around the instruments biologically safe and, at the same time, reduce the number of stray neutrons which get scattered into the detecting counter. In neutron crystallography, for which both of our instruments are intended, we have not found it necessary to have a continuously variable neutron wavelength. As a result we ch
a permanent value for the angle of reflexion at the m
chromator, thus permitting the shielding and the tunn
for the monochromatic beam to remain in a fixed posit
This greatly simplifies the construction of an efficient sh
The design aims at a value of 11° as the Bragg angle
reflexion at the monochromator, giving in practice a neu
wavelength of 1·06 Å when the 111 plane of a single cryst
lead is used. A wavelength of about this value is the r
useful for general purposes but for crystal structure d
minations by Fourier synthesis techniques there are ad
tages in using a shorter wavelength. For these cases
replace the lead crystal by a copper crystal, leaving
geometry of the apparatus unchanged and providing a w
length of 0·78 Å. The monochromatic beam travels tow
the diffracting sample on the table *P* by way of the cadm
lined tunnel *L* passing through the shield. This shield, w
has to absorb practically the whole of the neutron b
emerging from the collimator, is built up from a numbe
separate components. Immediately surrounding the m
chromator is a γ-ray shield composed for the most pa
lead blocks *H* 6 in. in thickness, except for the region
mediately in line with the collimator, where the shield con
of a block of tungsten alloy *J*. This is more expensive t
lead but possesses worthwhile advantages: besides bei
more effective γ-shield (with a density of 18 g cm^{-3} an
γ-attenuation by 10^7 times for an 8 in. length) it has a m
larger removal cross-section per unit volume for fast neutr
The main removal of fast neutrons then occurs by slo
them down in the hydrogeneous material which forms
bulk of the shield. A number of factors determine the ch
of this hydrogen-rich material. Safety considerations in
reactor shell preclude the use of paraffin wax and in
mable plastics. Water has good nuclear properties but
need for making shaped tanks to contain it, with accura
machined channels for the neutron beam makes it
attractive in practice. In fact we use a shield made of c
pressed wood: such materials have a hydrogen conten
$4{\cdot}8 \times 10^{22}$ atoms/cm^3, which is about 80% of the hydro
content of water, and they can be obtained commercial
sheets up to 6 in. in thickness which can be machined
handled quite easily. The density of these material
approximately 1·3 g cm^{-3} so they are slightly better t
water as a γ-shield. The outside dimensions of our shi
shown at *K* in Fig. 1, are 4 ft 8 in. in width and 3 ft 2
from front to back. The complete shielding assembly,
both instruments, is mounted on a steel framework whic
bolted to the reactor face and to the floor: the framewor
designed to support a total weight of 8 tons if needed.
effectiveness of the shielding is such that the level of radiat
with the collimator open and the reactor running at
power, does not exceed one maximum-permissible-l
except in the line of the tunnel which carries the mo
chromatic beam.

THE TWO INSTRUMENTS

The upper, "powder", spectrometer may be considere
two separate components.

A light alloy casting *Q* forms the housing for a wormw
about 2 ft 6 in. in diameter which runs on a double-
angular contact ball-race. The driving worm, together w
a motor for automatic rotation and a handwheel for mar
rotation, is mounted in a box *N* which is integral with
wormwheel housing. The sample table *P* is driven by s
tapes on ground steel drums giving the usual 2 : 1 reduct
in angular velocity and an epicyclic gear-train and cl

iit 360° rotation of the sample independently of the lar position of the detecting counter. The table is sub-ial enough to support heavy magnets without distortion. angular settings of the two rotating members, i.e. the ıle table and the counter, are displayed on screens on face of the box N by means of an optical projection m and silver-backed graduated glass circles. Each ement can be set to within 1′ of arc.

ie housing Q is supported at two points on spherical ng washers on the triangular shaped framework M h is attached to the front of the shielding table. A third t of support is given by a steel leg which can be placed ıe of two possible positions under the worm box. The e of two positions is provided to make more flexible zone of operation of any apparatus associated with the r beam hole.

present the main wormwheel is driven by a three-phase or at a speed of 6° per hour. A change of gear ratio a wide choice of speeds. In order to provide an angular ration of the diffraction pattern recording, or to operate matic counting equipment of various kinds, signals at °, $\frac{1}{3}$°, $\frac{1}{4}$° and $\frac{1}{12}$° intervals are produced from a repeater A gear-driven roller cam plate, operating on adjustable oswitches, provides for automatic reversal of the direction otation of the wormwheel at any angular setting between ° and +150° of the position of the undeviated incident ı.

ie counter track S, with its supporting framework, is a separate component of the instrument. It consists of a steel fabrication supported on five legs, with the actual surface of stainless steel. Any one of the five legs can emoved without causing any distortion of the track: ı, this provision is made to simplify the manoeuvres of instrument underneath. The counter R is a standard type shielded by boron carbide and synthetic resin and thene, the latter pair of materials offering a smaller fire-than does paraffin wax.

ie two-unit construction, with all the essential mechanical ponents concentrated in the housing Q, means that the ument could be employed in a variety of circumstances, example at reactor holes of various heights, with no ortant modifications other than supporting legs of rent length.

ie single-crystal instrument on the lower hole is an oved version of the one described by Bacon and Dyer(1) has been constructed with sufficient rigidity to enable it arry electromagnets on the sample table if required. It ists of a box of welded mild steel angle with top and om surfaces machined parallel. Plates are dowelled and d to the framework giving outside dimensions of 18 × 9 in.

ie more important details of the mechanical construction e instrument are indicated in Fig. 3. The main shaft (3) h carries the counter arm (4) runs in a taper-roller race (5) l into a boss welded to the underneath side of the top . Into the top of this shaft is fitted a second taper-roller (2) which carries the sample table (1) on the shaft (13): atter runs in two ball journal bearings, one (10) recessed e bottom of the main shaft and the other (14) in a boss ed by the bottom plate. The whole assembly is pre-ed to ensure accuracy and stability. A layshaft (8) is nted in sliding blocks to permit adjustment of the mesh ie spur gears which give the 2 : 1 reduction between the lar rotations of the main shaft and the sample table.

itomatic rotation of the counter is provided by a worm to the wormwheel (6) and an electromagnetic clutch (12) permits independent motion of either the sample table (1) or the counter assembly (7). The angular settings of the two latter are given by the graduated circles (9) which are viewed with an optical projector (11). Calibration signals are provided at intervals of 1°, $\frac{1}{2}$°, $\frac{1}{4}$° and 1′ of arc for control of automatic counting apparatus.

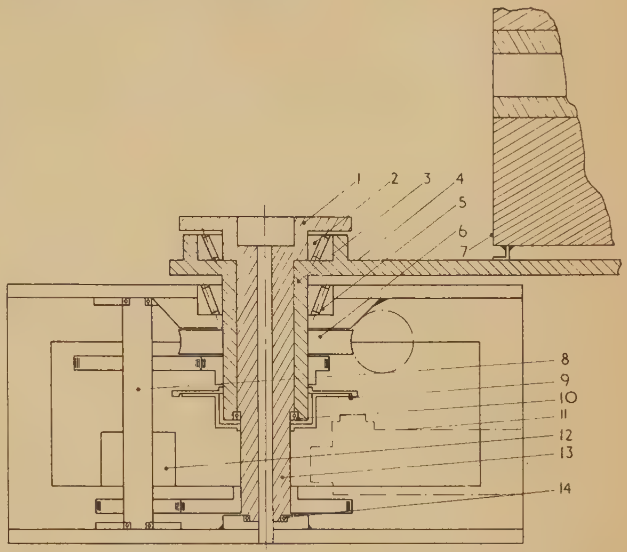


Fig. 3. Simplified diagram to indicate the mechanical construction of the single-crystal instrument. The numbered components are referred to in the text

Apart from their mechanical performance the user's interest in these instruments lies in the extent to which they widen the scope of neutron diffraction measurements. Compared with our earlier measurements, the use of the high-flux reactor has yielded an increase in neutron beam intensity by about twenty times. The significance of this has been commented upon in a previous note (Bacon and Dyer(2)). From a practical point of view, the choice of materials for sample holders and for any auxiliary equipment through which the neutron beam has to pass (such as Dewar vessels for low temperature measurements) assumes much more importance. In the past aluminium has been used widely in the construction of such apparatus and the diffraction pattern due to the aluminium has often been insignificant in comparison with the intensities given by the quite large amounts of sample material under observation. Now that sample sizes can be reduced by twenty times the diffraction pattern from the containing materials becomes very significant. The use of vanadium and the null-matrix alloys described by Sidhu and his co-workers(3) becomes very desirable and advantageous.

ACKNOWLEDGEMENTS

The authors wish to record their indebtedness to John Curran Ltd., Cardiff, who designed and constructed the large spectrometer and to Mr. W. F. Legge of A.E.R.E. for drawing Fig. 2.

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Hydraulic oscillator for the dynamic calibration of pressure recording systems

By A. W. Melville, A.M.I.E.E., Auckland Industrial Development Laboratories, Dept. Scientific and Industrial Research, Auckland, New Zealand

[*Paper received* 23 *February*, 1959]

An instrument is described which is designed to provide a constant-amplitude variable-frequency pressure cycle in a liquid, suitable for the determination of the frequency response of precision pressure transducers of low-volume displacement. The natural frequency of the fluid filled oscillator is 630 c/s.

It is common practice to record dynamic pressures by the use of precision pressure transducers having an extremely small volume displacement and a correspondingly high natural frequency. A particular application is the recording of blood-pressure pulses throughout the circulation system, either by the medium of intravenous and intra-arterial catheters or by direct needle puncture of vessels, usually during some surgical procedure, and it is inevitable that some flexible tubing is used in these systems. The overall frequency response of the system can be calculated, but this requires detailed information on the physical characteristics of all the component parts of the system, which may not be easily determined. It is attractive, therefore, to be able to measure the overall frequency response, and the equipment to be described will deliver constant-amplitude sine-wave alternating pressures in a liquid medium, usually water, with a frequency range extending from zero to several hundred cycles per second. It may also be used for delivering single or repetitive square-wave pressure pulses.

ELECTRO-DYNAMIC TRANSDUCER

An electro-dynamic vibration pick-up head, type PR9261 (by Philips) has been modified to operate as a pressure generator when energized from a suitable source. The pick-up head is normally supplied with the push-rod spring-loaded so that a force of 850 g is required to hold the ope ing coil in its centre position. An additional opposing sp has been installed so that the coil is normally located i mid position without any external force. A fluid cham shown in Fig. 1, which carries a stainless-steel diaphr with an effective diameter of 1·4 in. and a thickne 0·005 in., is attached coaxially to the body of the gener and the centre of the diaphragm is attached to the cen driven pin of the generator by a close-fitting collar and g screw. The fluid chamber has a short cylindrical glass and is completed by an end plate drilled to take t "Luer" adapters. The unit constitutes a rigid and sin hydraulic oscillator.

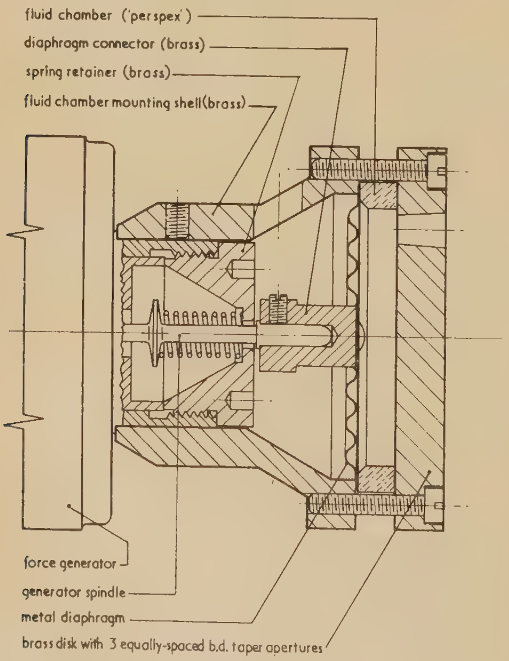
fluid chamber ('perspex')
diaphragm connector (brass)
spring retainer (brass)
fluid chamber mounting shell(brass)
force generator
generator spindle
metal diaphragm
brass disk with 3 equally-spaced b.d. taper apertures

Fig. 1. Fluid chamber

The inductance of the coil is approximately 220 mH the d.c. resistance is 2100 Ω. For the frequency r 0–100 c/s, the reactance of the coil can be neglected so the driving current is proportional to the applied volt The maximum permissible current is 20 mA r.m.s., at wh the peak force is 87 g and, with the diaphragm specified, natural frequency of the fluid-filled oscillator is 63 This was determined by viewing the oscillation of diaphragm driving rod with a microscope, and increasing frequency of the sinusoidal driving current until the resona peak was observed.

DRIVING AMPLIFIER

Driving current is derived from low-frequency oscilla type R. 666 (by Ediswan) and a special amplifier (Fig. One end of the driven coil is internally connected to the fra

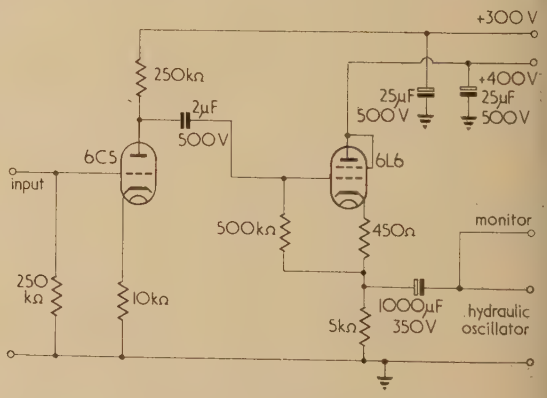

Fig. 2. Circuit for driving amplifier

of the hydraulic oscillator and it is necessary to keep liquid line, and hence the frame, at earth potential. cathode-follower power amplifier was built and the isolated from the direct current by a coupling capacitor 1000 μF comprising ten 100 μF, 350 V electrolytic capacit rallel. Slight attenuation at the lowest frequencies is cted by the method of monitoring the driving voltage. maximum undistorted peak-to-peak voltage available ; the hydraulic oscillator coil is 85 V and, with the ular diaphragm used, this produces a peak-to-peak ire of 30 mm of mercury as measured by a pressure lucer, type P23A (by Statham), connected directly to scillator by a rigid short tube.

PREPARATION FOR USE

eat care must be taken to exclude all air bubbles from uid-filled system, because the presence of even a very bubble is the equivalent of a great increase in the liance of the diaphragm. It is advisable to use water has been boiled and to which has been added a few per litre of a water softener. The output of the pressure ducer under test should be recorded with all its auxiliary ment complete in its final form.

APPLICATION

The inclusion in the hydraulic system of a component such as a length of plastic tubing having a relatively high compliance will reduce the amplitude of the pressure generated for a given diaphragm displacement, but this need not be a limitation provided the system is not frequency-discriminating within the required frequency range. This provision can easily be checked by monitoring the pressure at the source over the required frequency range with the system to be tested connected to the fluid chamber.

With the range of intracardiac catheters and thick-walled p.v.c. tubing used for direct needle puncture in medical applications, the flexibility of the tubing does not affect the uniform relationship between voltage input and pressure output within the range 0–50 c/s, and it is simpler to monitor the voltage appearing across the hydraulic oscillator coil. It has been found convenient to record the input and output simultaneously on a multi-channel recorder, and with the

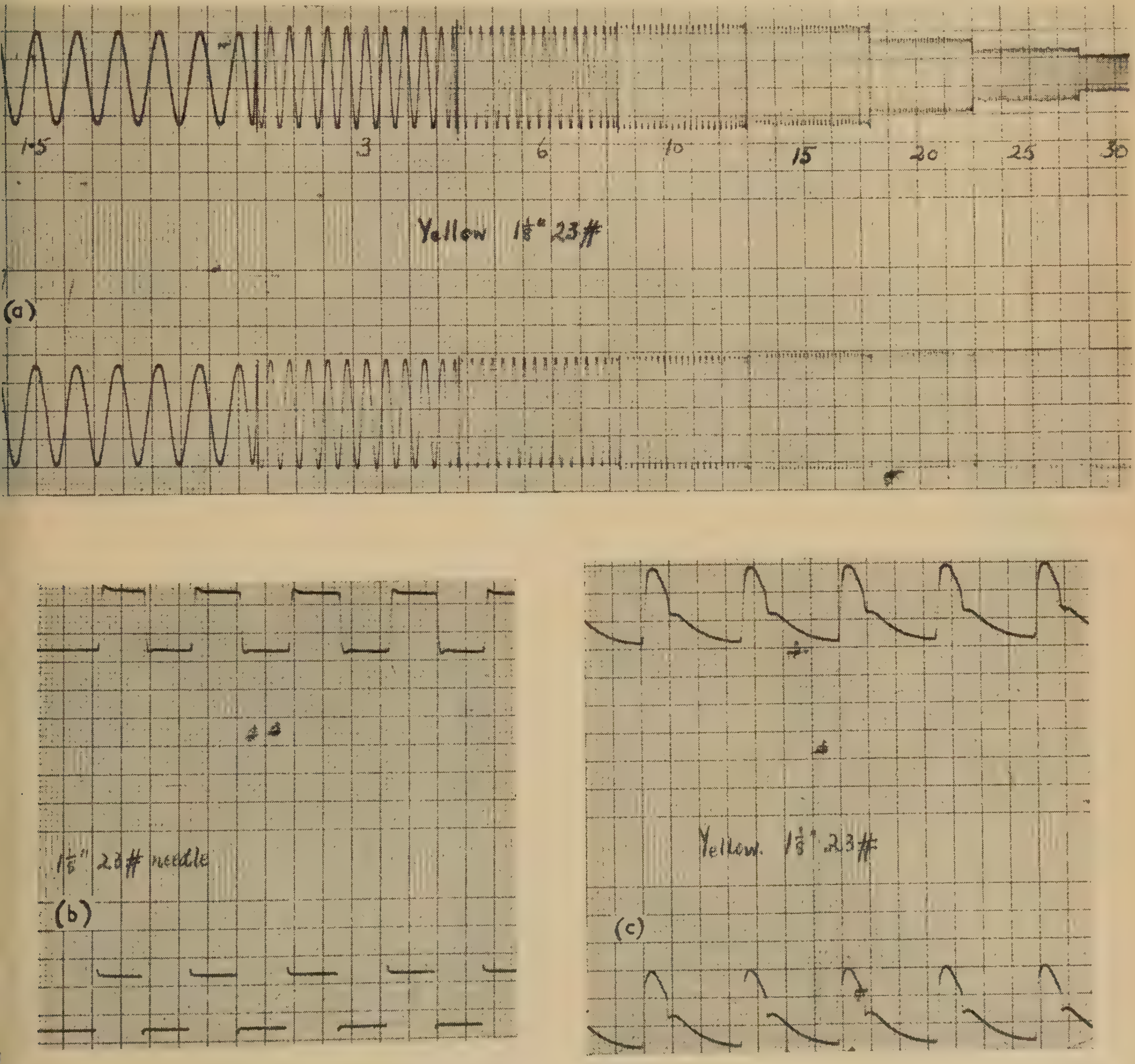

Fig. 3. Typical responses to variable-frequency pressure cycle (*a*) sine-wave, (*b*) square-wave, (*c*) synthesized wave simulating central arterial pulse

present instrument a twin-viso recorder (by Sanborn) is used. The frequency may be varied continuously although it is usually satisfactory to vary it in increments of 5 c/s and, for critical assessment, the ratio of output and input is plotted against frequency.

Single or repetitive square-wave pressure pulses or simulated waveforms of any type can be applied. Fig. 3(*a*) illustrates a typical recording of the response to a variable-frequency sine-wave pressure cycle of a system consisting hypodermic needle, $1\frac{1}{8}$ in. long, 23 gauge, and 100 cm p.v.c. tubing, 3 mm internal diameter, attached to a Stat pressure transducer, type P23A. The lower record is monitor signal. Fig. 3(*b*) illustrates the response of the s system to a square wave and Fig. 3(*c*) illustrates the resp to a synthesized waveform simulating the central art pulse.

Capillary pH electrode

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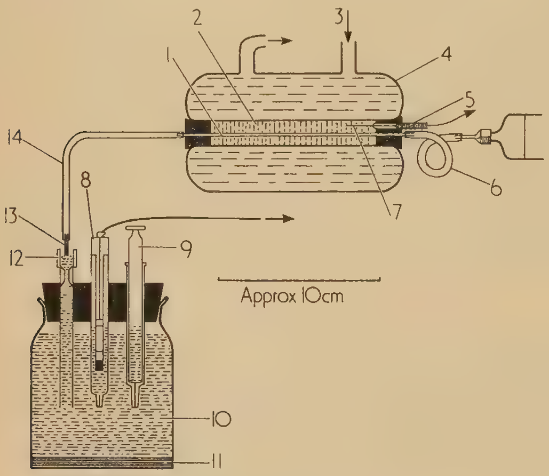
[*Paper first received* 10 *June, and in final form* 23 *June*, 1959]

A robust glass electrode and stable liquid junction is described. The precision for venous blood is ±0·0015 *p*H unit over the range 20 to 40° C under strictly anaerobic conditions.

Capillary electrodes use only small volumes of fluid, and have a large surface area. Fine capillary tubes are used, however, which block easily, are fragile and are not replaced with ease. This apparatus uses a robust capillary which is easily renewed. The liquid junction has been evolved using principles discussed by Mattock(1) to provide maximum stability with both aqueous solutions and whole blood.

The glass *p*H capillary (1) (140 × 1 mm o.d.) passes through silicone rubber bungs fitted into the inner tube of the all-glass envelope (4) (see the figure). No water can pass out of the glass envelope and cause electrical leakage. One bung carries a small glass tube through which passes a silver wire (7) soldered to the centre wire of a coaxial cable (5). The silver wire and cable are sealed carefully in the glass tube with Araldite. The silver wire is coated with silver chloride electrolytically. The compartment (2) is filled with 0·1 N hydrochloric acid. Elastic P.V.C. tubing (6) (o.d. 2 mm, i.d. 1 mm) connects one end of the capillary with a syringe, lubricated with silicone grease. The other end carries a similar P.V.C. tubing bent at right angles (14).



Capillary *p*H electrode

A fine polythene tube (o.d. 1 mm, i.d. 0·5 mm, length 10 mm) is pressed into the free end of the P.V.C. tube (13). This fine polythene tube forms the liquid junction with the reference electrode. The dimensions of the fine polythene tube are critical. They can be altered easily to suit particular conditions and instruments. Instability of *p*H readings is caused by a tube of too fine a bore and too long a le Drift is caused by excessive diffusion when the tube is wide, too short, or actual movement of the fluid colu occurs. The dimensions given are satisfactory for measurement of the *p*H of buffers, aqueous solutions whole blood at temperatures up to 40° C with one partic *p*H meter.

The reference electrode (8) passes through a rubber b into a 100 ml. wide-mouth bottle, containing satura potassium chloride (10) in contact with solid potass chloride (11). A syringe (9) passes through the bung the potassium chloride and a tube carrying a short length plastic tubing (12) emerges from the bung on the oppo side, as shown. Pressure on the syringe drives satura potassium chloride up into the plastic cup. The junctio formed by putting the cup just below the fine polyth tube (13) of the *p*H electrode. The potassium chlorid forced into the cup slowly so that the surface of the potass chloride solution just touches the tip of the fine tube. fusion currents are thereby avoided. The plastic cup, g tubing, syringe and rubber bung are coated with silic grease to stop seepage of saturated potassium chloride consequent electrical losses. The junction, when made stable to ±0·001 *p*H unit for 10 min. The readings reproducible to the same limits when the junction is m and remade frequently over a period of hours. The g capillary tube and plastic tubing connexions from the syri right through the apparatus to the fine plastic tip must leak. Any movement of the fluid at the liquid junc causes drift. The reference fluid is at room temperature, the large volume of saturated potassium chloride does alter in temperature under ordinary conditions.

The venous blood pH (at 37° C) of a dog recovering from car surgery

Sample	*p*H	*Post-operative time (min)*	*Condition of dog*
1	7·364	45	Lung inflation
2	7·301	75	Animal breathing on its own, but not conscious
3	7·290	105	
4	7·328	130	Reacting to stimuli
5	7·340	165	Recovery at rest
6	7·339	195	Recovery at rest
7	7·338	225	Recovery at rest

When MacInnes–Dole glass was used for the *p*H capill stable *p*H readings were obtained at room temperat ove this temperature, and particularly at 37° C, a pro- inced drift in the *p*H readings was obtained with buffers. [S glass capillaries (supplied by Messrs. Electronic :ruments Ltd.) were completely stable for four hours at C. One such capillary has been in use for 12 months sfactorily.

A Circotherm unit* circulates water from a 10 l. bath to *p*H unit (3). Ten millilitres of 1% methiolate are added the bath to inhibit moulds, and provide electrical con- tivity. The water is earthed through a rigid rod passing the bath. The water passing through the jacket of the apparatus provides very good electrical screening. The ıperature can be varied quickly and simply, and is con- led to ±0·01° C. The meter used was a 33B Vibron ctrometer and *p*H accessory unit.†

'his *p*H apparatus was designed for measuring the *p*H of od at 37° C under strictly anaerobic conditions. Blood, ected in a syringe, protected by mercury, can be delivered ough the capillary from the end furthest from the junction, ceded and followed by a column of mercury. When the rcury is expelled from the fine polythene tube, the tube is ed, and the liquid junction is made as described. No iculty has been experienced due to fouling of the junction h clotted blood. Readings are reproducible to ±0·0015 *p*H unit, at any desired temperature met with in pathological conditions. A representative series of whole blood *p*H readings is shown in the table. The blood was drawn into a siliconed heparinized syringe sealed with mercury. Small and significant changes in blood *p*H can be observed during the various phases of cardio-respiratory investigations.

The electrode is cleaned by drawing distilled water and 0·1 N hydrochloric acid through the capillary tube. The acid is left in the capillary and plastic tube when the electrode is not in use, and then both ends of the tubing are closed with plastic plugs. If the capillary is grossly contaminated with dried blood or other protein containing material, 1% pepsin in 0·1 N hydrochloric acid is an efficient cleaning agent. This is followed by frequent washing with 0·1 N hydrochloric acid.

ACKNOWLEDGEMENTS

It is a pleasure to record my indebtedness to Dr. G. Mattock and Messrs. Electronic Instruments Ltd. for help during the development of this electrode, the Cardiac Research Unit of The Hospital for Sick Children, London, for the figures in the table and the Department of Medical Illustration for the illustration.

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Messrs. Shandon Scientific Co. Ltd., London, S.W.7, England.
Messrs. Electronic Instruments Ltd., Richmond, England.

Apparatus for the measurement of internal friction and dynamic Young's modulus at kilocycle frequencies

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[*Paper first received* 13 *April, and in final form* 4 *June*, 1959]

Electrostatic transducers are used to excite and detect longitudinal vibrations in a rod specimen clamped at its mid-point. The electronic circuit forms a regenerative loop in which oscillations occur at the resonance frequency of the specimen. A method of calculating the amplitude of the specimen oscillations is given. Measurements of the internal friction and dynamic Young's modulus, which can be made as a function of strain amplitude and temperature up to 500° C, are illustrated by some preliminary observations on beryllium.

INTRODUCTION

e internal friction of a material is a measure of its rate self absorption of vibrational energy. It can be determined m the rate of decrease in the amplitude of freely decaying :illations or, when this rate is very high, from the width the resonance frequency peak. At kilocycle frequencies of ration the energy absorbed is due, in general, to the tion of dislocations and their interaction with impurity ms.(1) A study of the changes in internal friction with ain and temperature should yield information on the regation of impurity atoms to dislocations which is an portant factor in current theories of the deformation of tals. The dynamic Young's modulus can be calculated m measurements of the fundamental resonance frequency the specimen.

There are several methods of producing vibrations at ocycle frequencies and measuring the internal friction. e of the most popular is to make the specimen part of a nposite oscillator(2, 3) in which several components includ- a piezo-electric crystal are cemented together and the ole assembly is made to vibrate at one of its resonance frequencies. This type of apparatus can only be used over a small temperature range which is limited by the mechanical properties of the cement. It has the further disadvantage that the action of cementing the parts together can introduce local strains into the specimen and so increase the internal friction. Specimens in the form of rods or flat strips can be excited into bending vibration by supporting them horizontally in fine wire stirrups.(4) The stirrups must be placed some small distance from a nodal point so that they can be used to induce and detect the vibrations. In this case the supports themselves contribute to the energy lost by the specimen. Corrections can, however, be applied to the measured value of the internal friction.(5)

In this apparatus, which is similar to that used elsewhere(6–8) the energy losses external to the specimen are reduced to a minimum. The cylindrical specimen, 10 to 20 cm long and 0·6 cm in diameter, is held at its mid-point which is a nodal point for longitudinal resonance. The rod is set into resonant vibration by the electrostatic forces produced when an alternating voltage is applied between the specimen and a suitably placed electrode. The vibrations of the rod are detected by a condenser microphone formed by a second electrode placed near the other end of the rod. In other versions of this apparatus the driving voltage is supplied by a high stability oscillator tuned to the resonance frequency of the specimen. When the specimen has a very low internal friction the resonance peak is very narrow and it is often difficult to maintain specimen vibrations at constant amplitude.(9) The new feature of this apparatus is that the electronic circuitry forms a regenerative loop in which oscillations occur automatically at the resonance frequency of the specimen. By this means the rod can be maintained indefinitely at a constant amplitude of oscillation. Details of a similar application of a regenerative circuit have recently been published by Thompson and Glass.(10)

MECHANICAL CONSTRUCTION

The main details of the mechanical construction are shown in Fig. 1. Only one-half of the apparatus is shown as the other end is constructed in exactly the same manner. A long stainless steel tube around which is placed a furnace forms the basis of the apparatus. This tube has a water cooling jacket at either end and terminates in a large chamber in which electrical connexions are made and to which the vacuum pumps are connected. The electrical leads are taken out of this chamber through glass insulated seals. The furnace is fixed to a rigid aluminium angle base and the ends of the stainless steel tube are free to move on sliding supports resting on the base. This arrangement reduces distortion of the tube due to thermal expansion at the higher temperatures. The whole apparatus is supported horizontally on soft rubber pads to reduce the effect of external vibrations.

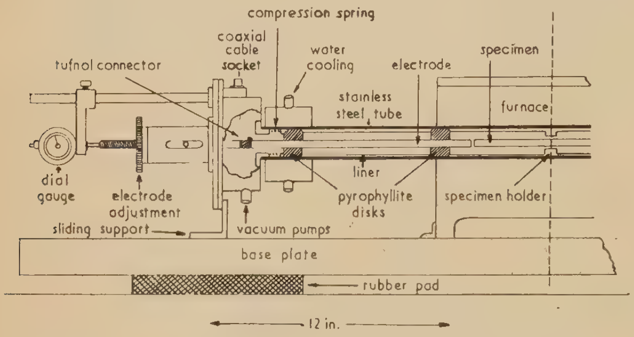

Fig. 1. Main details of mechanical construction

The tubular steel specimen holder has three stainless steel screws symmetrically placed in its central plane which are used to clamp the specimen at its mid-point. The procedure for mounting the specimen in the holder is important. Two brass bungs which are a good sliding fit inside the holder and have central holes to support the specimen are used to keep the specimen and holder coaxial while the clamping screws are carefully tightened. The brass bungs can then be removed without disturbing the specimen. The line of contact between the stainless steel screws and the cylindrical surface of the specimen is 1 mm long. The central portion of the holder also carries grub screws for securing a thermocouple and earth lead.

The specimen holder, pyrophyllite disks and liners are assembled end to end and the whole unit placed in the stainless steel tube. The edges of each piece are chamfered so that when the assembly is compressed longitudinally the separate pieces line up coaxially. The ends of the system are sealed by means of O-rings and the end plates which ca the electrodes and their screw adjustments. The electro are stainless steel rods 1 cm in diameter and are connec to the end plate assembly through electrically insulat Tufnol blocks. The gap between the electrode and specim is set with the aid of a micrometer type dial gauge read to 2 μ.

The effectiveness of this design and method of assembly ensuring that the polished end faces of the specimen a electrode are parallel is shown by measurement of the capa tance between the faces as a function of their separati Typical results are shown in Fig. 2. The measured separat

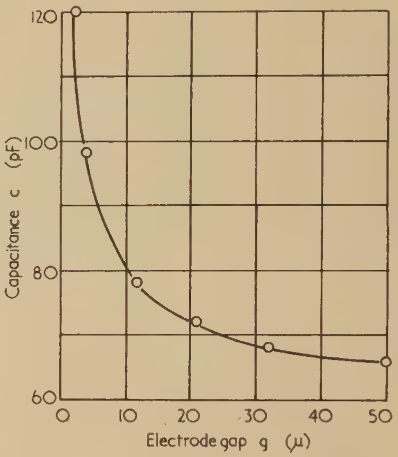

Fig. 2. Calibration graph

is the minimum distance between the electrode and speci faces. When the minimum separation is 2 μ calculation sho that the capacitance is equivalent to a mean separation of 4 If the surfaces are perfectly smooth and plain the an between them is less than 10^{-3} rad.

ELECTRONIC CIRCUITS

A block diagram of the apparatus is shown in Fig. When setting up the electrode-specimen gap the driving a detecting electrodes are connected directly to the appropria proximity meters. The proximity meter consists of a 500 k oscillator whose output is applied across a fixed capacit in series with the electrode capacitance to earth. T

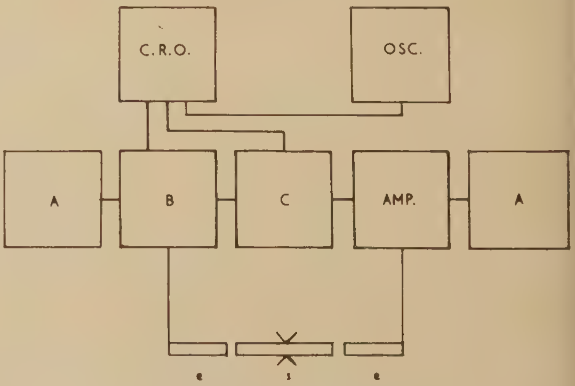

Fig. 3. Block diagram of apparatus

C.R.O., cathode-ray oscilloscope; *OSC.*, decade oscillator; *A*, bias control and proximity meter; *B*, cathode follower and phase shifter; *C*, electronic switch; *e*, electrode; *s*, specimen.

citor chain forms a voltage divider and the voltage een the electrode and earth is indicated on a meter. meter reading decreases as the electrode-specimen gap eases and is zero when the electrode is in contact with specimen. The proximity meter units also contain the rols for the d.c. bias which is applied to the electrodes ng normal operation.

fter the electrode-specimen gaps have been set to the ired values the driving and detecting electrodes are nected directly to the amplifier and phase shifter respecy. The latter unit is necessary as the complete circuit only be regenerative when the total phase shift is an gral multiple of 360°. The input to the phase shifter is e through a cathode follower (Fig. 4), having an input edance of 50 MΩ. The output of the cathode follower is nected to the primary winding of the phase shift transner and can also be displayed on a cathode-ray oscillooe. The centre tapping of the secondary winding of the se shift transformer is earthed and a variable resistor and acitor are connected in series between the ends of the dings. The output is taken from the centre of this chain earth. The variable resistor provides a fine phase control coarse adjustments are made by switching various acitors into the circuit. A phase shift of up to 180° can obtained and when a further 180° is required the signal be passed through an additional stage of amplification.

n the electronic switch a three-way manual switch directly trols a gate valve. In the "off" position the switch shorts output of the amplifier unit to earth through a $0\cdot5\ \mu$F acitor ensuring that no oscillatory signal is applied to the ing electrode. When the switch is in the "on" position gate valve is held open and the regenerative circuit is npleted. In the third switch position a multivibrator ch produces square wave pulses with time intervals cted by switches on the front panel of the unit controls gate valve. The multivibrator is synchronized with the al in the regenerative circuit and its negative pulse which es the gate valve can be used to trigger the oscilloscope e base.

he regenerative circuit is completed by amplification of signal and its application, through a biasing circuit ilar to that shown in Fig. 4, to the driving electrode. A -stage amplifier is used which has a frequency range of to 40 kc/s. When the regenerative loop is complete llations at the natural resonance frequency of the specin are built up from noise in the electronic circuits. The plitude of the oscillations is limited by the gain of the plifier and can be controlled by variation of either the bias on the driving electrode or the gap between this trode and the specimen.

CALIBRATION OF THE DETECTOR CIRCUIT

he detection electrode circuit is shown in Fig. 4. C is sum of the capacitances of the connecting cable, electrode earth and electrode to specimen. When the specimen is ating

$$C = C_0 + C_1 \sin pt \tag{1}$$

re C_0 is a constant and C_1 the maximum change in C duced by the vibration at a frequency f equal to $p/2\pi$. vided that the input impedance of the cathode follower is ch greater than the bias resistance R and $C_1 \ll C_0$ the ory of a condenser microphone shows that the signal age is given by

$$e = EC_1R/(C_0^2R^2 + 1/p^2)^{1/2} \tag{2}$$

where E is the biasing voltage and R the bias resistance. Equation (2) can be rewritten in the form

$$(EC_1/C_0)^2(1/e)^2 = 1 + (1/C_0pR)^2 \tag{3}$$

The alternating signal e is a maximum e' when R is infinite and

$$e' = EC_1/C_0 \tag{4}$$

The ratio e/e' represents the efficiency of the circuit and is equal to

$$e/e' = 2\pi fC_0R/(1 + 4\pi^2f^2C_0^2R^2)^{1/2} \tag{5}$$

It can be shown that the efficiency is very nearly 100% for circuits in which the product $fC_0R \geqslant 1$. Providing that the circuit components satisfy this relationship calculation of the amplitude of oscillation of the specimen from the measured signal can be based on equation (4). The product fC_0R can only be increased by increasing R for an increase in C_0 reduces the signal voltage e'. The resistance R must be much less than the input impedance of the cathode follower and to reduce the noise level in the circuit its value is kept to a minimum consistent with 100% efficiency, i.e. $R = 1/fC_0$. In this apparatus typical values are $C_0 = 60$ pF and $f = 30$ kc/s $R = 0\cdot5$ MΩ.

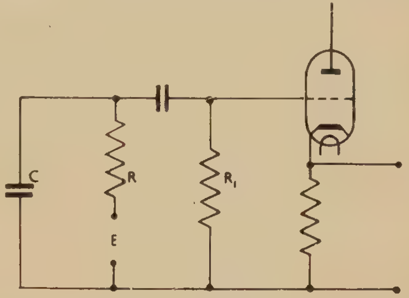

Fig. 4. Detecting electrode circuit

C, capacitance between electrode and earth; R, bias resistance; E, bias voltage; R_1, 50 MΩ.

From the setting of the gap "g" between the detection electrode and the specimen and the slope (dC/dg) of the calibration graph (Fig. 2) at the point $C = C_0$, C_1 can be expressed in terms of the amplitude of oscillation a of the end of the specimen. In this manner the observed signal e'' is given by

$$e'' = (aKE/C_0)(dC/dg) \tag{6}$$

where $K < 1$ and equal to the amplification of the cathode follower stage. The form of this equation has been verified experimentally. The received signal is directly proportional to the bias voltage and increases rapidly as the electrode-specimen gap is decreased. Substituting normally used values in equation (8), i.e. $K = 0\cdot7$, $E = 300$ V, $C_0 = 60$ pF and $(dC/dg) = 0\cdot25$ pF/μ when the amplitude of oscillation of the end of the specimen is ± 12 Å the received signal is ± 1 MV. This sensitivity can be increased by using a smaller electrode-specimen gap.

MEASUREMENT OF THE INTERNAL FRICTION AND YOUNG'S MODULUS

The coefficient of internal friction ϕ is determined from the rate of decay of the oscillations in the specimen when the regenerative circuit is broken. $\pi\phi$ is defined as the natural logarithm of the ratio of successive amplitudes in the decaying oscillation. This relationship can be written in the form

$$\phi = (1/\pi ft) \ln (A/B) \tag{7}$$

where f is the resonance frequency and t the time taken for the oscillations to decay from amplitude A to amplitude B.

The signal from the detection electrode is displayed on an oscilloscope and when the internal friction is small, ϕ less than 10^{-5}, a stop-watch is used to measure the time taken for the oscillations to decay between two selected amplitudes which differ by a factor of ten or more. At higher values of ϕ, a 35 mm oscilloscope camera having a variable speed drive is used to record the decay. The film record is projected on to a graduated screen at known magnification and the relevant measurements made.

The electronic switch in the regenerative circuit provides an alternative method of measuring the higher decay rates. This switch repetitively opens and closes the regenerative circuit at selected time intervals. The oscillations build up when the switch is closed and decay when it is opened. As the switch opens a pulse triggers the oscilloscope time base, which can be adjusted so that the whole of the decaying waveform is displayed. A single frame camera record can then be made and analysed as previously described.

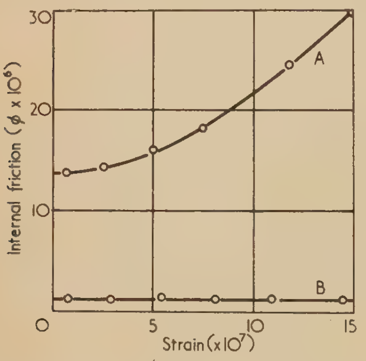

Fig. 5. The strain dependence of the interval friction of beryllium at 20° C

Curve A, as received; curve B, after annealing.

Measurements of the frequency of the oscillations is required for calculation of the internal friction and determination of the dynamic Young's modulus of the specimen. The resonance frequency under stable oscillating conditions is compared, by means of Lissajou's figures, with the output of a calibrated oscillator. The dynamic Young's modulus E is determined from the equation

$$E = 4\rho L^2 f^2 \tag{8}$$

in which ρ and L are the density and length of the specimen respectively and f is the resonance frequency. This appr mation to the precise theory can be used since the lengt the rod specimen is much greater than its diameter.(11)

The equations developed above can be used to calculate internal friction at various strain amplitudes. Typical res are shown in Fig. 5. The specimen used was a hot-pres warm extruded rod of beryllium. In the "as received" c dition the specimen showed a strain-dependent inte friction at 20° C which was eliminated by a short annea 500° C. From measurement of the resonance freque length and density of the beryllium rods Young's modu was found to be 43 × 10⁶ lb/in.² This value is in g agreement with that obtained by Gold.(12)

The regenerative circuit allows the oscillations of the specimens to be maintained indefinitely at a selected amplit even when the internal friction coefficient is as low as 1 Measurements of internal friction and resonance freque have been made up to temperatures of 500° C with apparatus.

ACKNOWLEDGEMENTS

We thank Dr. T. P. Hughes for his interest and encoura ment in this work and the Chairman of Tube Investm Ltd. for permission to publish this paper.

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Precision microphotometer for use with a Vickers projection microscope

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A microphotometer has been designed to measure photographic density and density gradients in autoradiographs. The equipment is designed to be used with a Vickers projection microscope, being particularly useful in the quantitative study of autoradiographs from metallurgical specimens. Results can be obtained over a magnification range of 18·6 to 400 times. The photographic density is measured by balancing the output of two photomultipliers, one in the incident beam and one in the transmitted beam. Densities measured on this instrument were compared with the quoted values on a standardized density wedge and gave a standard deviation of 0·006.

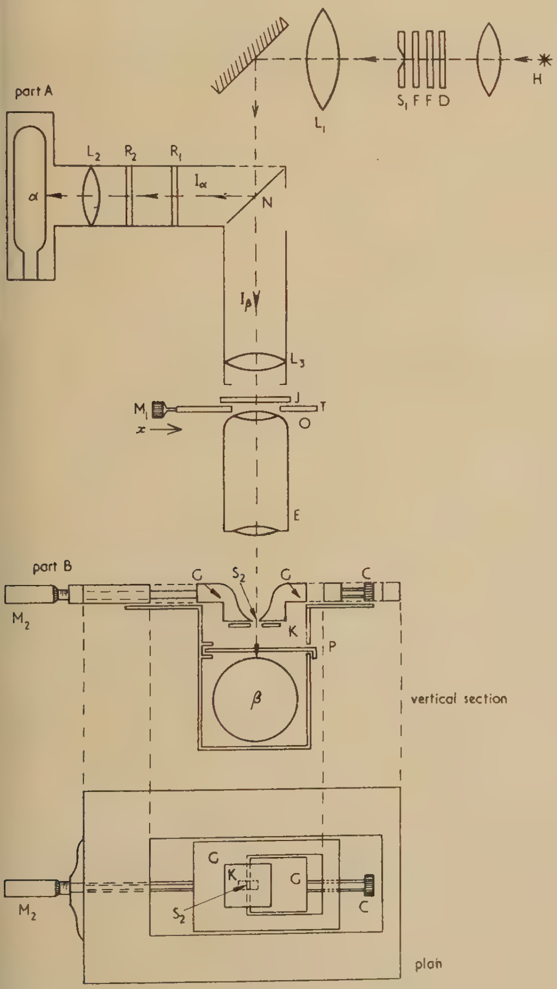
1. INTRODUCTION

A photographic emulsion can be used to measure the intensities of visible and ionizing radiation and this requires the measurement of the transmittance or density of a photograph or autoradiograph.(1–3) The light which is transmitted consists of two parts, namely a component continuing in direction of the incident beam and a diffuse component. $_0I_x$ is the flux measured by a receiver at co-ordinate x acr the incident beam when a clear plate is in position and is the corresponding flux when a photograph is in the sa ion the photographic density is $\log_{10} 1/T_x$ where T_x is I_x. Since the exact ratio of the light collected by the suring device to that incident on the photograph depends ne geometry of the whole optical system this must remain tant throughout the whole operation.

ne microphotometer described here has been designed icularly for quantitative autoradiography. It consists of e attachments (Fig. 1) which convert a Vickers projection oscope into a microphotometer. The slit S_1 defines the of the incident beam and is added to the components he lamp condenser support. Part *A* splits the incident n and compensates for changes in the light source nsity; it is attached to the usual microscope substage. *B* measures the transmitted intensity and replaces the e holder.

2. DESCRIPTION OF APPARATUS

1 *The optical system.* Light from the source at *H* . 1) passes through a diffusing screen *D*, filters *F* and the able entrance slit S_1, which defines geometrically the entry he beam of light into the microscope and photometer. r passing through the condensing lens L_1, the beam is at an inclined glass slide *N* into a beam I_α used for parison with a transmitted beam I_β which passes through autoradiograph. The beam I_α passes through two roid sheets R_1 and R_2, one of which can be rotated to change the intensity of the light beam focused by the lens L_2 upon the photomultiplier α (Mazda 27.M3). The beam I_β passes through a similar lens L_3 which focuses an image of the entrance slit S_1, upon the autoradiograph at *J*. The objective *O* and eyepiece *E* of the microscope, produce an image of the autoradiograph and the slit S_1 in the plane of the slit S_2. S_2 defines the exit cone of light from the whole system. The intensity of this exit beam is measured on photomultiplier β. The optical system above the beam splitter is, with the exception of the slit S_1, the normal illuminating system of a Vickers projection microscope.



ig. 1. Arrangement of microphotometer (not to scale)

The output of the two photomultipliers is balanced in a bridge circuit (Fig. 2). The ratio I_α/I_β is proportional to the ratio of the resistances in the two arms.

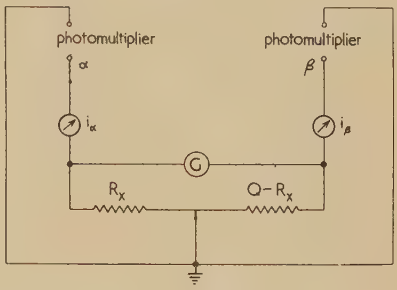


Fig. 2. Circuit diagram

The optical system described above serves to define the geometry of the light incident upon and transmitted through the autoradiograph, provided that the extent of the light source is sufficient completely to fill the entrance pupil of the system.

2.2 *The light source.* It is necessary to consider the variations with time of:

(*a*) The spectral distribution of the light source.

(*b*) The intensity incident on the autoradiograph at a given position due to variations in the position and excitation characteristics of the light source.

(*c*) The distribution of intensity across the entrance pupil of the system.

At a given time, changes in the spectral distribution of the light source will affect both photomultipliers. The differences in the ratios of the sensitivities to different wavelengths between two photomultipliers of the same manufacture are small. Therefore (*a*) may be assumed not to affect the ratio I_α/I_β. Similarly variations of intensity at a given position on the autoradiograph at a given wavelength due to variations in the excitation characteristics of the source do not affect the ratio I_α/I_β.

I_α and I_β are measured together on a bridge circuit and the ratio is therefore independent of the time. However, variations in the position of the light source will affect each photomultiplier differently and will also cause (*c*) to vary with time. It is therefore important to use a light source whose position does not vary with time. The principle source of light in a Point-o-lite lamp is two fixed incandescent balls and it is therefore suitable as a light source for the microphotometer.

2.3 *Setting up conditions.* To set up the microphotometer the Point-o-lite lamp and slit S_1 are turned into the axial position and part *A* of the microphotometer attached to the stage support. The lens L_3 is focused to bring an image of the slit S_1 on to the autoradiograph *J* on the stage *T*. The condensing lens L_1 is usually retained in the system except when the autoradiograph is to be scanned at the highest magnifications. The removal of this lens reduces the size of the image of S_1 upon the autoradiograph J and consequently increases $_0I$. The required magnification of the autoradiograph is produced in the usual way by a suitable combination of objective, eyepiece and bellows extension. Part B of the microphotometer is then slid into position in the plate holder of the microscope. The width of the slit S_2 is adjusted by turning the screw C and can be set at any width in the range 0·05 to 6 mm. Various slit lengths up to 25 mm can be selected by sliding one of five masks K into the carriage G. The light-tight box containing the photomultiplier β is then screwed on the slit carriage and the light-tight slide P withdrawn.

The intensity of illumination falling on the photomultiplier β is adjusted by inserting light filters at F (Fig. 1) to give a current $i_\beta = 2$ or $4\ \mu$A, depending on the magnification for a portion of the autoradiograph of minimum density. The fine adjustment of the current is made by changing the e.h.t. supply to the photomultiplier within the limits 0·7 to 1·0 kV. The e.h.t. supply to the photomultiplier α is set to the same value, and the Polaroid R_2 is adjusted to give a current $i_\alpha = i_\beta/2$. The remainder of the circuit comprises a Muirhead potential divider in the form of a dial box, a galvanometer of sensitivity 2900 mm/μA and an e.h.t. supply to each photomultiplier derived from two potentiometers run from a single power pack. The balance point for the position of minimum density is obtained under these conditions. The settings of filters, Polaroid and e.h.t. then remain unchanged throughout the subsequent scanning of the autoradiograph.

If the photometer is to be used for comparisons over large areas of autoradiograph, the slit S_2 is opened as wide as possible and balance points found as each autoradiograph is put on the stage in turn. For more detailed examination the slit size S_2 is reduced and the autoradiograph is scanned in one of two ways.

In the "fixed film" method, the autoradiograph position is fixed and the exit slit S_2 is moved across the magnified image of the autoradiograph by the micrometer M_2 (Fig. 1). Therefore unit movement of the exit slit corresponds to a movement across the autoradiograph of $1/M$ where M = linear magnification. Consequently changes in position of the slit S_2 and errors in the micrometer setting are reduced with respect to the autoradiograph by $1/M$. This is the most convenient general method and is applicable to all magnifications greater than 27. The incident intensity $_0I_x$ varies across the portion of autoradiograph which is scanned. It is necessary to know values of $_0I_x$ for each setting of the micrometer M_2 in order to be able to calculate the photographic density of the autoradiograph. These values may be obtained by measuring the apparent density of another portion of the autoradiograph, known to be of uniform density, at the same settings of the micrometer M_2. This gives values of density above a background equal to that of the uniform autoradiograph. When the magnification is less than ×27, the maximum magnified image of the slit S_1 ceases to fill the scanning range of the slit S_2. For general inspection of a large area of autoradiograph at low magnifications it is more convenient to use a moving film method of scanning.

In the "moving film" method the autoradiograph is moved with the micrometer M_1 on the stage T, so that different points of the projected image of the autoradiograph are brought in front of the slit S_2 which is fixed. The method is not suitable where great precision is required but has the advantage that it is independent of the variations of $_0I_x$ si the same portion of the incident beam is used for all positi of the autoradiograph.

3. RESULTS

3.1 *Method of calculation.* If F is the total flux from lamp and the optical arrangements are fixed, so that distribution of flux anywhere in the system is fixed, current i_α produced by the multipler α is proportional to The light intensity incident at any point x on the autorac graph under measurement is proportional to F but constant of proportionality varies with x because the inten of illumination is not completely uniform. The current fr the multiplier β, namely i_β, may also vary with x even if transmittance of the autoradiograph is constant, because light falling on the photomultiplier cathode will vary w the position of the slit S_2. The ratio of the two currents i is therefore proportional to $1/T_xP_x$. That is,

$$1/T_x = KP_xi_\alpha/i_\beta$$

where K is a constant.

If now we take an autoradiograph of uniform transmitta T and measure values of the currents, say i'_α and i'_β, at position x,

$$1/T = KP_xi'_\alpha/i'_\beta$$

and it follows that

$$T/T_x = i_\alpha i'_\beta/i_\beta i'_\alpha$$

It is clear from the circuit diagram (Fig. 2) that when bridge is balanced (for the autoradiograph of transmitta T_x)

$$i_\alpha/i_\beta = (Q/R_x) - 1$$

where Q is the total resistance of the slide wire.

Thus

$$T/T_x = \{(Q/R_x) - 1\}/\{(Q/R'_x) - 1\}$$

or, in terms of densities,

$$D_x = \log_{10}\{(Q/R_x) - 1\}/\{(Q/R'_x) - 1\} + D$$

The performance of the instrument has been investiga using a standard stepped wedge for densities up to 2·00 linear magnifications from 18 to 440 times. Prelimin experiments showed that systematic errors occurred in density measurements when the absolute values of currents in the two photomultipliers for a minimum dens setting were uncontrolled.

3.2 *Variations in the systematic error and sensitivity w* $i_\alpha \,.\, i_\beta$*—Operating conditions.* The variations of the systema error have been investigated at three magnifications cover the working range of the instrument, as a function of i_β the reference density and i_α at a constant S_2 slit s 3·4 × 1·6 mm. Four densities were measured with ea pair of current settings. The results for one value of i_α shown in Table 1 where the systematic error is expressed the mean percentage error of the four densities, i.e. $\frac{100}{4}\Sigma$

Similar variations in the systematic error were found at the values of i_α. Table 1 shows that the minimum systema error occurs for i'_β in the range 2 to 4 μA.

The expression $\frac{Q}{R_x} - 1$ is very insensitive to changes in or i_β at constant i_α, i_β respectively when $R_x \rightarrow Q$ and $\frac{1}{\frac{Q}{R_x}}$

milarly insensitive as $R_x \to 0$. Therefore the ratio of i_α/i_β hosen to avoid readings close to either end of the bridge. ractice for a density range 0 to 2 the ratio i_α/i'_β has been fined to the range $\frac{1}{4}$ to $\frac{1}{2}$.

Table 1. *Variations in systematic error* $\frac{\Delta D}{D}$ %

= 2 μA

i_β	×18·6	×200	×440
1 μA	−1·3	−3·2	−3·1
2	+0·5	−0·9	−0·9
4	+1·1	+0·5	−0·1
8	+2·0	+1·3	+1·0
16	+3·2	+6·5	—

.3 *Accuracy and reproducibility of density.* Tests of uracy and reproducibility were made on the stepped wedge ıg the moving film method. Small slow drifts in the tocurrents have been found to occur even after many ırs of running. In practice this does not introduce a ıificant error in the value obtained for the density, unless appreciable drift occurs between obtaining a reading for required density and the corresponding reading on the te of uniform density. At a given magnification, and ing of S_2, a complete run consisted of measuring in licate the densities of four steps in order of increasing ısity with clear plate readings immediately before and after h pair of readings at a given density to minimize errors to drift. Five complete runs were made at each magni- tion or change in size of slit S_2. The values of i_α and i_β re readjusted if necessary at the beginning of each run. results are summarized in Table 2.

Table 2. *Accuracy and reproducibility of density*

Magnification	18·6	32	67·5	120	380	440
S_2 *Width*	0·6	1·6	0·6	0·6	0·6	1·6
S_2 *Length*	3·4	3·4	3·4	3·4	3·4	3·4
*dge density**						
·057	1·067	1·071	1·066	1·067	1·063	1·082
·396	1·403	1·402	1·400	1·401	1·401	1·392
·682	1·690	1·689	1·690	1·693	1·700	1·685
·00	1·991	1·989	2·005	2·000	2·020	2·004
ndard deviation	0·005	0·002	0·002	0·002	0·006	—

* As measured on a Hilger microphotometer.

The standard deviation of the densities at each magni- ation has been calculated using the mean range method,(4) t is, the range of the five measurements at each given ısity is determined. The standard deviation is 0·4 × mean ıge. A more fundamental test of the instrument was tained by moving the slit S_2 across the magnified image of azor blade edge. Knowing the width of the slit (=2 mm) d the position of the image of the razor blade edge with pect to the slit absolute values of ${}_0I_x/{}_1I_x$ can be calculated various positions of the slit and compared with the asured values. This gave a standard deviation of 0·006.

3.3 *The accuracy and reproducibility of a density distri- tion.* This has been investigated by scanning the photo- aphic image of a spectral line placed at two independent sitions within the range of movement of the slit S_2 at a gnification ×120. The magnified image of the spectral e was placed at position 1 (x = about 6·5 μ) and values R_β measured at selected positions x of the slit S_2. The age was moved to position 2 (x = about 11 μ) and R_β asured again at appropriate positions. The spectral line s then replaced by a portion of plate chosen to represent unexposed photographic emulsion and R_α measured over the range of values of x covered by positions 1, 2. At ×120 the graininess of the photographic emulsion was apparent. Therefore small-scale fluctuations in R_α were not considered to be significant and a smooth curve was drawn through the experimental points. Smoothed values of R_α obtained from this curve have been used as described in section 3.1 to calculate densities.

The density profiles of the spectral line measured at the two positions are compared in Fig. 3, where the origins of the abscissae have been arranged to make the two positions of maximum density coincide.

4. DISCUSSION AND CONCLUSIONS

The systematic error increases rapidly with increasing i_β. In section 3.2 a linear relation between the photomultiplier current and the incident light was assumed.

Suppose $i \doteq$ constant $f(i)I$.

Then

$$\frac{{}_0I_x}{{}_1I_x} = \text{constant}\ \frac{i_\alpha f(i_\alpha)}{i_\beta f(i_\beta)} \tag{6}$$

and

$$\frac{{}_0I_x}{{}_1I'_x} = \text{constant}\ \frac{i'_\alpha f(i'_\alpha)}{i'_\beta f(i'_\beta)}$$

Therefore

$$D_x = \log_{10}\left(\frac{i_\alpha}{i_\beta}\cdot\frac{i'_\beta}{i'_\alpha}\right) + D + \log_{10}\left\{\frac{f(i_\alpha)}{f(i'_\alpha)}\cdot\frac{f(i'_\beta)}{f(i_\beta)}\right\}$$

Since the variations in the incident intensity are small, we may put $\frac{f(i_\alpha)}{f(i'_\alpha)} = 1$. A separate experiment showed that $\frac{f(i'_\beta)}{f(i_\beta)} \geqslant 1$ and increased with increasing i'_β. Therefore, for large values of i'_β the measured densities will be greater than true densities and will make positive contributions to the mean error in Table 1. As i'_β is lowered, the ratio $i_\beta/i_{dark\ current}$ tends to unity resulting in the measured densities becoming progressively smaller than the true densities, and these will make negative contributions to the mean error in Table 1. Therefore there is a minimum in the mean error as a function of i'_β for the density range 0 to 2·00.

The results in section 3·3 indicate that when the electrical parameters are controlled within the ranges already discussed, densities in the range 0 to 2 can be measured with a standard deviation better than 0·006.

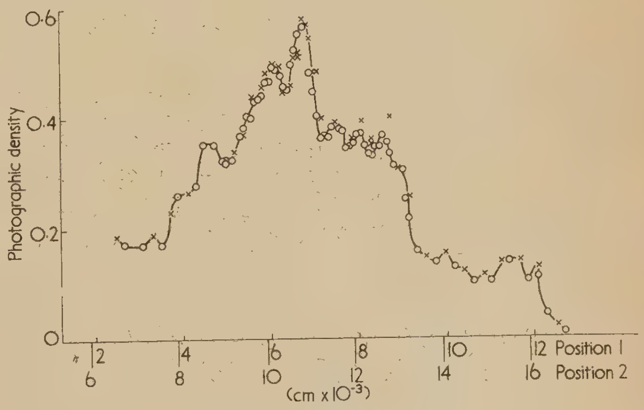


Fig. 3. Spectral line scan

×, first scan; ○, second scan.

The slow drifts found to occur in the photomultiplier currents could in principle reduce the accuracy of measurement of density distributions since it is not often possible to follow each density measurement immediately by a measurement of the reference density. The extent of this error can be deduced from a comparison of the density profiles of the spectral line (Fig. 3). In this experiment the two profiles followed by the background were measured in a period of about 3 h. Although this time is longer than would occur in normal use, the two profiles agree at almost all points to within 1%. Therefore the slow drift and any variations in the distribution of light intensity across the scanning field with time do not introduce an appreciable additio error.

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Continuous deionized water washing system for semiconductor devices

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Designed for use on a batch production basis, the apparatus provides for the recirculating water to pass through an ion exchange resin after washing the devices. Two conductivity cells, one on either side of the washing point, measure the specific resistivity of the circulating water; this is $20 \times 10^6\ \Omega$ cm at 18° C in water about to pass over the devices, i.e. deionized water. The apparatus is constructed mainly of polythene and P.V.C. to avoid contamination of the water.

1. INTRODUCTION

It has been observed(1) that the electrical properties of semiconductor devices are improved by washing them in a stream of deionized water. This improvement is probably due to the removal of ions adsorbed on the surface of the device. Since it is uneconomical in production to use a stream of deionized water over a device and then run the water to waste, some method of recirculating the water is necessary. The apparatus described in this paper is constructed mainly of polythene and P.V.C., to avoid contaminating the deionized water, and circulates the water by means of a pump through a mixed bed ion exchange resin column, over the devices and back to the column.

Some general considerations on the preparation of high purity water by ion exchange resins have been given recently(2) and though the results are not strictly applicable to a recirculating apparatus, it is interesting to observe that they are often similar to those found with the present apparatus.

2. DESCRIPTION OF THE APPARATUS

Fig. 1 shows the general arrangement of the equipment. Water is continuously pumped around a closed circuit in the direction indicated. After being drawn through the column of Amberlite monobed resin MB-1 into the pump the water is forced into the washer where it passes over the articles to be washed and then returns to the deionizing column to be recirculated. On entering and leaving the washer the water is checked for resistivity by conductivity cells permanently fitted in the circuit.

As mentioned earlier, the equipment is made almost entirely of polythene and P.V.C., the exceptions are the conductivity cells, a Perspex screw cap on the actual washer and a sintered glass filter in the deionizing column. The screw cap, filter and conductivity cell body could be made of polythene if required but there is no evidence as yet that these items adversely affect the performance.

The centrifugal pump was supplied, complete with integ motor, by Plastic Construction Co. Ltd., of Birmingham. conventional 3-phase motor drives the self-priming pump give a maximum delivery of 1·75 gallons per min again a pressure head of 10 ft or a suction head of 5 ft. pump body and rotor are of rigid P.V.C.; a plastic sealin ring maintains an efficient seal where the drive spindle ente

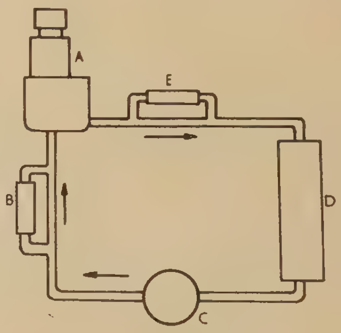

Fig. 1. Layout of washer

A, washer; *B*, conductivity cell no. 1; *C*, pump; *D*, ion exchange column; *E*, conductivity cell no. 2.

the pump body. A plastic sleeve shrunk on the metal driv spindle prevents both contamination of the water an corrosion of the spindle.

The washer itself is depicted in Fig. 2; the constructio can be best appreciated from a consideration of its operatio A stream of water is forced up the central jet pipe to diverted on to the device by the water deflector housed the Perspex screw cap. After washing over the devices th now impure water cascades down into the reservoir to drawn off through the outlet on its way to the deionizin column. The jet pipe is supported at three places along i length; at the base and at two centralizing disks of th reservoir. The pipe, disks and reservoir body are of pol and welded as one. Large holes in the two centralizing allow the water an unrestricted passage into the reser- A shoulder near the outlet of the vertical jet pipe orts the device holder which is removable for reloading vhich is also of polythene. Six or more holes equispaced nd a pitch circle in this holder loosely locate the lead of the device mount.

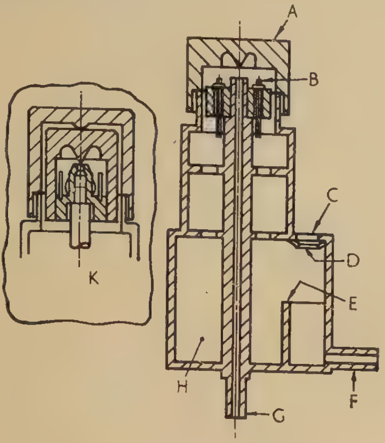

Fig. 2. Detail of washer

removable screw-cap; *B*, devices in detachable holder; hole for additional conductivity cell; *D*, polythene washer l; *E*, weir; *F*, outlet; *G*, inlet; *H*, reservoir; *K*, alternative cap and holder for slice washing.

e water deflector for device washing is shown in section ırt of the screw cap and comprises a right circular cone ling into the vertical wall of a circular recess. The apex e cone spreads the oncoming jet which is then turned ıe blending radius on to the walls of the recess to fall in iform circle over the devices. Since the devices are osed around a circle and the matching deflector has a lar outlet, rotational displacement of the holder does ıffect the line-up of the two. Clearly, however, applica- will arise where a specially shaped deflector must line up ately with the holder. The washing of semiconductor rial in slice form, for instance, presents this set of con- ns; slots in the holder must be accurately located under rresponding set of flats in the deflector recess. The ctor cone in this case is replaced by a square pyramid. der to maintain correct alinement the deflector and slice er are made integral as shown in inset, Fig. 2.

ıe cup-shaped weir covering the reservoir outlet forms st for a third conductivity cell and ensures that the cell with circulating rather than static water. The hole in over immediately above this weir can be plugged when additional cell is not required. A second hole in the r will accommodate a thermometer. A third hole takes ug fitted with a tall vent pipe to maintain atmospheric ure above the surface of the water without spillage. polythene pipe is covered by a loose cap of the same rial to prevent the ingress of settling dust. These three have thin polythene washers welded to the underside ıe cover to provide efficient sealing of the plugs or ssories.

g. 3 shows the arrangement of the deionizing filter; hene is again the predominant material. The open end e tube takes a screwed ring which retains and seals the e of the inlet pipe; this detachable connexion facilitates cement of the ion exchange resin. The other end of the is fabricated by welding an outlet cup to the tube body after inserting the glass filter. This is a standard sintered glass filter of porosity "O"; its purpose here is to allow the water to pass whilst retaining the column of ion exchange resin.

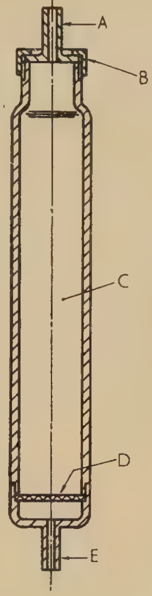

Fig. 3. Ion exchange column

A, inlet; *B*, screwed retaining ring; *C*, Amberlite monobed resin MB-1; *D*, sintered glass filter; *E*, outlet.

Connexions between the washer, pump and filter are made with P.V.C. tubing. This is bonded to the polythene nozzles and forced over the glass ends of the conductivity cells after heating the glass slightly in a flame.

3. MEASUREMENT OF THE SPECIFIC RESISTIVITY OF THE RECIRCULATING DEIONIZED WATER

The greater the specific resistivity of water, the freer it is from dissolved ionic impurities. However, water itself ionizes very slightly into hydrogen and hydroxyl ions. This ionization is temperature dependent and it has been calculated that the specific resistivity of pure water is $26{\cdot}3 \times 10^6\ \Omega$ cm at 18° C.

The specific resistivity of water is normally determined from alternating current measurements on a conductivity cell containing two platinum electrodes in a fixed geometry and the cell is calibrated using a solution of known resistivity. It is considered,(3) however, that it is best to determine specific resistivity when greater than one megohm by a direct current method in which the potential difference required to pass a small current through the cell is measured. The circuit used for this measurement in the present work is shown in Fig. 4, and is similar to one used by Krauss and Fuoss.(4) Pye flow type conductivity cells with cell constants of approxi-

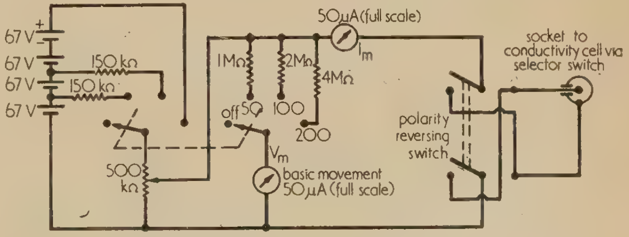
67 V
67 V
67 V
67 V
+
−
150 kΩ
150 kΩ
500 kΩ
1MΩ
2MΩ
4MΩ
off
50
100
200
50μA(full scale)
I_m
V_m
basic movement 50μA (full scale)
polarity reversing switch
socket to conductivity cell via selector switch

Fig. 4. Direct current apparatus for measuring conductivity of deionized water

mately unity and with bright platinum electrodes were used. The current passed through the conductivity cells was kept below 5 μA to avoid polarization of their electrodes. The reversing switch shown in the circuit was used to confirm that by reversing the polarity of the electrodes the current did not change in magnitude, thus suggesting that polarization was not significant. The instrument was calibrated with a 10 MΩ resistor, accurate to ±5%, by setting the current at a given division on the microammeter and measuring the voltage. The measurement of specific resistivity was carried out by substituting a conductivity cell for the resistor and setting the current to one of the calibrated divisions.

The results showed that at 18° C the equilibrium value of the specific resistivity of the water flowing through conductivity cell no. 1 was 20×10^6 Ω cm and of that flowing through cell no. 2 was 16×10^6 Ω cm. This difference is due presumably to the uptake by the water of carbon dioxide before it flowed through cell no. 2.

When water was recirculating through the apparatus, its specific resistivity increased to the maximum values for the two cells within two minutes. When semiconductor devices were being washed the specific resistivity of the water flov through conductivity cell no. 2 reached its maximum v usually within five minutes.

ACKNOWLEDGEMENTS

We should like to thank J. Bickley for his help in c structing the apparatus for accurately measuring the spe resistivity. Acknowledgement is also made to the Admir for permission to publish this paper.

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Characteristics of spark counters

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The spark counter, operating as an α-particle detector, has been studied extensively both with respect to the corona current in a given gas, and for different gases. The performance of a single wire counter was first studied, and then the experiments were extended to multiple wire counters. Nitrogen showed good characteristics with a single-wire counter, but failed for multiple wires, whereas dry air showed the best characteristics with a counter with six wires.

The fundamental principles underlying the operation of the spark counter as an α-particle detector are not yet very clear, even though several investigators$^{(1-6)}$ have studied the features of its working conditions. In the present work, experiments have been made to improve its efficiency, particularly in the case of multiple-wire counters. Many difficulties occurred during the work, especially that of making the wires all operate simultaneously. Furthermore, a comprehensive study of the counter has been attempted, the work being divided into the two sections: (*a*) experiments on a single-wire counter, and (*b*) those on multiple counters.

SINGLE-WIRE COUNTERS

Apparatus and procedure. The counter consists of a wire stretched above and parallel to a horizontal brass plate at a distance of 1 mm from it. The whole system was enclosed in a metal box having two opposite windows, which enabled adjustments to be made to the wire-to-plate distance. (This distance was adjusted to exactly 1 mm.) The plate was mounted on an insulator at the bottom of the box, and connected to the negative terminal of a stabilized power supply. The wire was also insulated from the two sides of the box, being fixed to them by supports made of special high-insulation material. One end of the wire was connected through a spring which kept the wire taut and the other end passed to a scaler where the sparks were recorded. An old polonium source was introduced into the chamber through a special device on the upper face and a screw was provided to vary the distance from the source to the counter. liminary experiments with wires of different materials sho that tungsten gave the best working conditions.

The corona current and its dependence on applied vo and plate dimensions. For the operation of the instrun as a counter, the method of procedure was to vary potential on the plate until a corona appeared around wire. The α-particle source was then moved towards space between the wire and the plate. This caused int ionization at a point in the corona, which develops first a streamer, and then into a spark—hence the name s counter for the instrument.

It was first required to study the behaviour of the cor current without the interference from the source, and t to study the developments leading to sparks as the so approaches the wire-plate gap.

If the variation of the current with the potential differe V applied between the wire and the plate, is first conside then

$$V_e = V - IR,$$

where V_e is the effective voltage, R is the quenching resist (1·7 MΩ in the present apparatus), and I is the cur between the wire and the plate. As the applied potenti is increased, I also increases, so that V_e will increase b amount smaller than V. It was found that, although increases with V for small potentials, a stage was reac when further increases in V were completely balanced increases in IR and V_e remained a constant, which characteristic of the counter.

Variations in the breadth of the plate were next investiga seven plates of different breadths, no significant changes ed in the corona current except that it became unsteady the breadth was less than 1 cm.

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ie study of length variation was more complicated use it was necessary to take into consideration the fact the discharge of electricity is confined to that portion ie wire covered by the luminous glow. If the length of late is varied, the length of wire operating increases and, fore, the corona current increases. Plates of the same dth, having lengths from 1·3 to 4·7 cm have been used. corona current was measured as a function of the applied ntial for five different lengths and the resulting curves shown in Fig. 1. These curves show the following

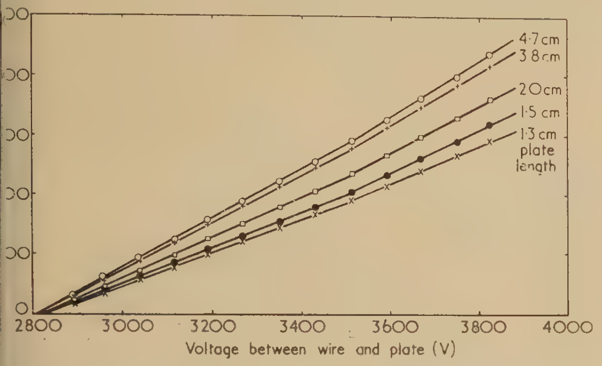
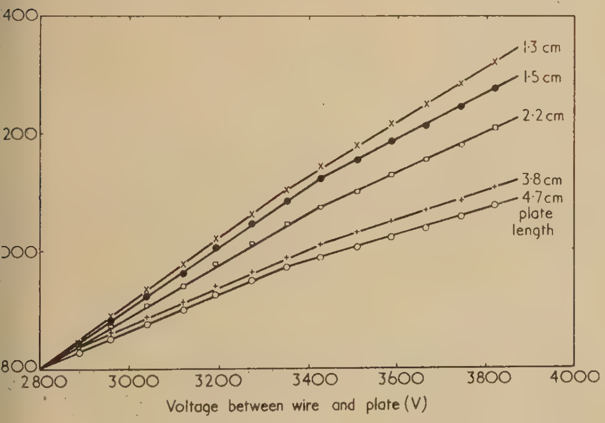


Fig. 1. Effect of length of plate on characteristics

iviour: (1) for a given applied potential, the current eases with the length of the plate (that is, with the nsion of the luminous glow) as was expected; (2) there marked change at a potential of 3440 V, after which the e of the curves is found to increase. (This potential esponds approximately to the beginning of the flat ion in the curves of Fig. 3, which is discussed later.)

ig. 2 shows the V_e/V curves for the different lengths. slopes of these curves decreases with increasing length of e and there is again the discontinuity at 3440 V, the slope becoming smaller.



ig. 2. Variation of V_e with V_a for different plate lengths

inally, Saha(6) has made a special study of the effect of ing the quenching resistance R for a constant length of e. This is the alternative method of varying the IR term quation (1).

ounting-rate characteristics. An old α-particle source of nium was used. It was covered by a special gun designed to give a homogeneous beam of α-particles through a cylindrical hole 1 mm in diameter and of length 6 mm, the source being at a distance of 3·3 cm from the wire. When the source carrier, without the source, was brought near to the gap no counts were observed, indicating that there was no radioactivity in the carrier. With the source at 3·3 cm from the wire, a suitable number of sparks was obtained. Experiments were performed with three different gases and typical curves are given in Fig. 3.

The curves for dry air are similar to those obtained by previous observers. The number of sparks per minute first increases with V to a potential of 3040 V, then decreases, and finally becomes almost constant for a range of the order of 800 V between 3150 V and the limit of the range of the instruments used (the maximum potential in the supply was 4 kV). It was noticed, however, that oxides of nitrogen were formed during the discharge and, to reduce these as much as possible, the dry air was supplied to the apparatus as a continuous stream. It was also found that the brass plate immediately under the wire became covered with a brown deposit. The band was broadest in the middle and tapering slightly at the ends. This deposit may be the cause of the smaller number of sparks for air compared with that for pure nitrogen (which is evident from Fig. 3).

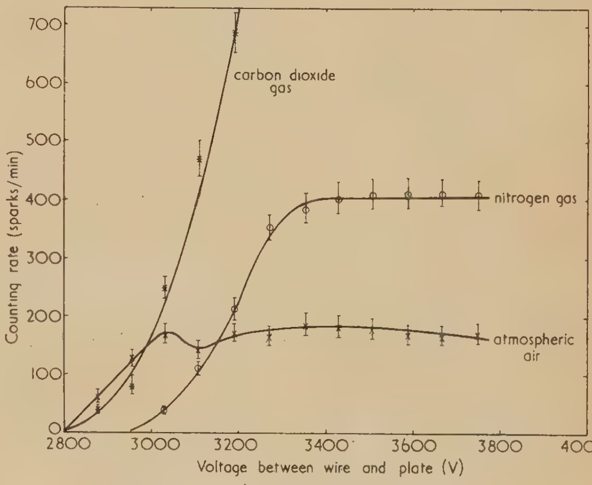


Fig. 3. Spark count for various gases

For nitrogen, the flat portion of the curve in Fig. 3 does not begin until 3360 V, which is higher than the corresponding voltage for air. The number of counts is greater, however, and the slope of the flat portion is smaller than that of air.

For carbon dioxide, there were no sparks at all when the gas was pure and dry. When mixed with air, however, sparks began to be produced when the proportion of carbon dioxide to air was three to one. At a ratio of one to one, the range of the flat portion was very small and, after it, a complete discharge occurred. Carbon dioxide seems, therefore, to be quite unsuitable for use in the spark counter for α-particle detection.

MULTIPLE WIRE COUNTERS

In experiments made without the source, it was found that care had to be taken to make the working potential the same for each wire separately. The test for this was that every wire had the same amount of glow around it. It was found also that for distances greater than 2·5 mm between two successive wires, there was no appreciable variation of the corona current.

Experiments with the source. The wires were so adjusted that all were active at the same time. The number of wires was varied and a comprehensive set of results was obtained for dry air and is given in the table and in Fig. 4.

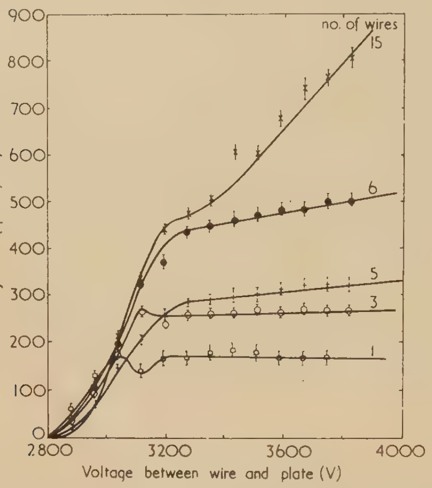


Fig. 4. Spark count for different numbers of wires

The number of counts for the flat portion of the curve increases with the number of wires. At the same time, however, the slope of this portion of the curve increases from 0·4% for one wire, to 2% for fifteen wires. The extent of the flat portion also decreases above six wires, becoming only of the order of 160 V for twelve wires, and the general behaviour of this counter is unstable. Increasing the number of wires, therefore, ultimately leads to instability.

Results for multiple-wire counters

Number of wires	*Distance between two wires (mm)*	*Dimensions of flat part of curve*		
		Length (V)	*Slope (%)*	*No. of cou per minut at centre*
15	1	240	2	190
12	2·5	160	4	480
9	2	200	1	180
6	5	560	0·4	480
3	8	720	0·1	265
1	—	480	0·4	225

For nitrogen, no corresponding set of results was attaina because a complete discharge was found with the slope the curve becoming very high.

CONCLUSION

An α-particle spark counter with a single wire is efficient when used with nitrogen gas. A counter w multiple wires, however, performs better with dry air it is most efficient when designed with six wires set 5 apart.

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Device for the estimation of the rate of work on passing air by sine wave flow

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In investigating the resistance to airflow of equipment for respiratory protection, it is often desirable to know the rate of work done in sine wave flow. A device is described which allows this estimation to be made without intermediate calculation from the results of simple experiments carried out under conditions of constant rates of flow. If these results, when plotted on logarithmic paper as pressure against rate of flow, lie on a straight line, the device allows a second line to be drawn which represents the rate of work done in sine wave flow plotted against the volume moved per minute.

In testing gas-masks and other breathing apparatus, it is often desirable to estimate the rate of work done against frictional resistance when air is passed through them in sine wave flow. This can be achieved by recording pressure volume diagrams but the technique is time-consuming and the necessary equipment is not readily available to all. It is, however, easy, and requires only simple equipment, to investigate resistance at various constant rates of flow. The device described here makes it possible to estimate from these simple results the rate of work which would be done in sine wave flow, and obviates the calculations.

At the relevant rates of flow in either direction the ae dynamic behaviour of the respiratory apparatus can approximated satisfactorily by the equation

$$P = k_n V^n$$

where P = pressure, k_n = a constant, V = rate of fl (volume), and n = a constant in the range 1–2. In suc system, when air is passed in the same direction by sine wa flow, the amount of work done per minute in that directi (half-cycles),

$$W_{HC/min} = \frac{k_n \pi^n V^{(n+1)}}{2} \int_0^{\pi} \sin^{(n+1)} x \,.\, dx$$

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re x is an angle. The value of the term $\int_0^{\pi} \sin^{(n+1)} x \, . \, dx$ be derived with satisfactory accuracy for any value of n a nomogram. When the results of the constant flow riments are plotted on logarithmic paper they fall on a of gradient n, intercepting the line $V = 1$ at a point se ordinate value is log k_n. Let this point be p. Similarly ation (2) is represented by a line of gradient $(n + 1)$ ing $V = 1$ at an ordinate value

$$\log k_n + n \log \pi - \log 2 + \log \left[\int_0^{\pi} \sin^{(n+1)} x \, . \, dx \right]$$

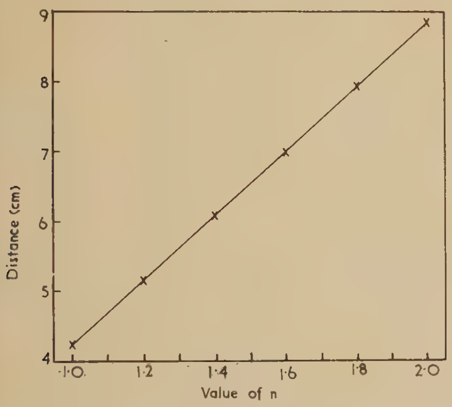
this point be w. The difference between the two ordinates

$$n \log \pi - \log 2 + \log \left[\int_0^{\pi} \sin^{(n+1)} x \, . \, dx \right]$$

n n has values between 1 and 2 the term

$$\log \left[\int_0^{\pi} \sin^{(n+1)} x \, . \, dx \right]$$

be assumed for the present purpose to be a linear function . Also, the term is small relative to $n \log \pi$, so that the r resulting from the assumption is, at its greatest, less 1%. Therefore the difference between the ordinate es of the points p, w can be expressed in the form $(an + b)$, re a and b are constants, and the actual distance pw on logarithmic paper can also be expressed as $(An + B)$, n A and B are constants which take into account the of the paper. Fig. 1 shows the distance pw plotted nst n for the construction of the device described below.



ig. 1. The distance pw in centimetres for values of n the range 1–2. (The values shown are not of general pplicability since they include a small correction factor for the flow-meter used)

n Fig. 2 let pa represent the abscissa, rate of flow V; pb line $V = 1$; pp' the results of the constant flow experints. The perpendicular distance from the point x to pb e distance A. The perpendicular distance from x to wd e distance B. The point w is thus defined whose distance ve p is $(An + B)$ (B having a negative value). It is essary to construct a line of gradient $(n + 1)$ through point. Let the distance from the point c to the line pb A. Then the gradient of wc is $\dfrac{\text{distance } cd}{2A}$. This will have value $(n + 1)$ when $cd = 2A(n + 1)$, that is, when $= 2A(n + 1) + An + B = 3An + 2A + B$. If the distance from the point f to the line pb is $3A$, the height of f above pa is $3An$. The point g is thus below the desired point c by the distance $(2A + B)$ (B having a negative value).

Making use of these principles a device has been constructed to facilitate drawing the line wc, and is shown in Fig. 3. It is composed of five pieces, made of either one or two layers of Perspex so that they may slide over or impinge

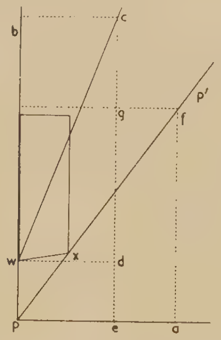


Fig. 2. Basic principles of the device (see text)

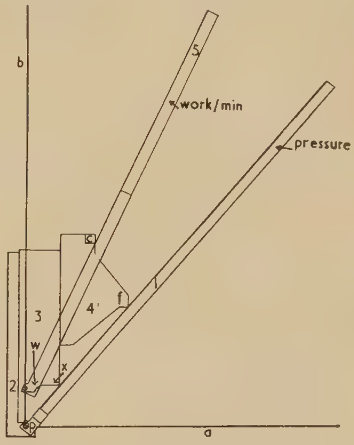


Fig. 3. The device. p, w are pivotal points. The letters correspond to those in Fig. 2. [The length of the arm (1) is 60 cm]

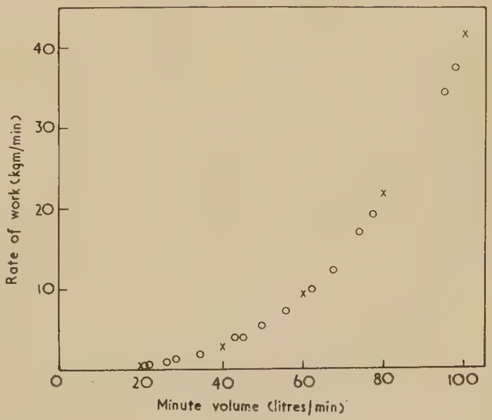


Fig. 4. Rate of work done against the frictional resistance of a mines rescue breathing apparatus is plotted against volume moved per minute

×, derived by use of the device described
○, derived from pressure-volume diagrams

on the appropriate part of the contiguous pieces. A portion of (1) overlies (2), (5) overlies (3) and (4) while point c is the corner of a small Perspex block mounted proud of the rest of (4). (1) is pivoted on (2) at p, (5) is pivoted on (3) at w. The abscissal distances are $wx = A$; $wc = 2A$; $wf = 3A$. The ordinate distances are $wx = B$, $fc = (2A + B)$ (B having a negative value).

The use of the device is simple. The results of the constant flow experiments are plotted on the appropriate logarithmic paper as pressure against rate of flow.

The upper border of (1) is laid along the points so that the pivot p lies on $V = 1$; (2) is adjusted so that its long border is parallel to $V = 1$; (3) is slid down, rubbing against (2) until the point x impinges on (1); (4) is slid down, rubbing against (3) until the point f impinges on (1); (5) is rotated upwards, until its upper surface impinges against the projection C. The line drawn along the upper border of (5) is that desired and represents the rate of work done at any minute volume in passing air in that one direction.

If the abscissal scale represents flow in litres per mi and the ordinate represents pressure in centimetres of wa then the same ordinate scale represents rate of work kilogram centimetres per minute in passing air in that direction.

In the context of the accuracy required the actual manip tion of the device does not introduce an appreciable er A typical example of its use is shown in Fig. 4. The cro represent estimates made by applying the device to the res of constant flow experiments on a mines rescue breath apparatus. The circles show the results of estimates m by recording pressure-volume diagrams on the sa apparatus using a sine wave pump. The agreemen satisfactory.

ACKNOWLEDGEMENTS

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Simple electronic scanning system for the X-ray microanalyser

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An electrostatic deflector system is described for use with the X-ray microanalyser. This enables the electron probe to be scanned across the specimen electrically using either manual or electronic control. The application of this system to a current metallurgical problem is described and certain statistical limitations of the method are mentioned.

In previous papers,(1, 2) the design and operation of an X-ray microanalyser developed at the A.E.I. Research Laboratory was described. This instrument enables a point spectrochemical analysis to be made in the manner first described by Castaing and Guinier,(3) and subsequently developed by Castaing(4) and others.(5, 6) In all these instruments, a fine electron probe of about a micron in diameter is directed at the desired point of the specimen with the aid of an optical microscope; the resulting characteristic X-rays are then analysed in a conventional X-ray spectrometer.

Cosslett and Duncumb(7) modified the method of viewing the specimen by replacing the optical microscope by an electron scanning microscope of the type originally devised by von Ardenne(8) and recently improved by McMullan,(9) with the additional facility of image formation by a selected X-ray emission line.

The electron scanning microscope, in principle, has a better resolving power than the optical microscope, although this cannot be exploited immediately because the resolution limit of the X-ray microanalyser is set at present by other factors, notably by electron scattering in the specimen. Future developments, however, are likely to lead to an improvement in resolution to a point where the optical microscope is no longer adequate by itself.

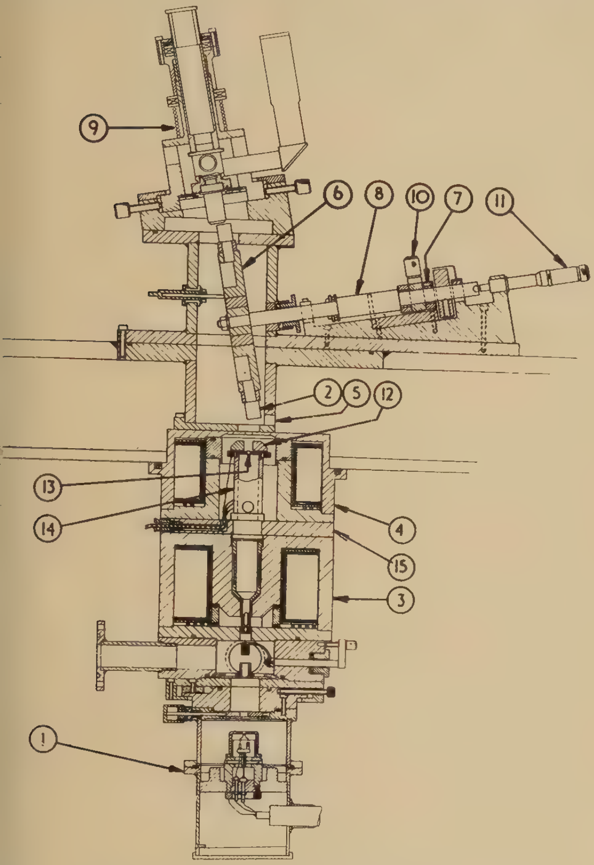
One of the drawbacks of the electron scanning microscope has been the complexity of the beam-deflector system and its associated electronic equipment. The present investigation is concerned with the design and construction of a simple electronic scanning and display system which is intended to supplement the information obtained from the optical microscope. Such a system has been incorporated into the existing apparatus. In addition to being a useful adjunct in analysing specimens, the equipment has also been used to investigate experimentally the limitations of the scann method as set by statistical fluctuations in the record process. These arise partly from the random nature of signal from the X-ray detector and partly from the rand background of non-characteristic radiation (*Bremsstrahl* from the target arising from the electron bombardment the target.

GENERAL CONSTRUCTION

An idea of the general arrangement of the electron pro forming system and the optical viewing arrangements m be gained from Fig. 1 which shows the general constructi An electron gun 1 forms an electron source some 50–10 in diameter; this is reduced to a spot half a micron in c meter at the target 2 by means of two lenses 3 and 4, latter being a long-working-distance lens of low aberration

The X-rays excited in the specimen pass through a t "Melinex" window 5 into a conventional bent crys spectrometer where they are analysed. The specimens mounted on a drum 6 which can be rotated accurat through 180 deg. by means of a lever system 7 actuating shaft 8 mounted on V-blocks. In operation, the micro-a to be analysed is brought under the cross-wires of the opti microscope 9 by means of the micrometers 10 and 11; drum is then rotated through 180 deg. against the fi stops in order to place the chosen part of the specimen un the electron probe. This method, first proposed by M. E. Haine, separates the optical from the electron-opti system allowing the best design to be used for each. alinement of the two systems can be carried out quite simp by using as a marker the small patch of carbon contaminati that forms on a suitable target, for example, copper.

The final demagnifying lens 4 has a wide bore (6 eter) on the side facing the electron gun, and a small (6 mm diameter) on the target side. The small bore as a magnetic screen to prevent the presence of ferro- etic specimens from upsetting the lens field. The large is necessary for electron-optical reasons to reduce the rical aberration to a minimum. This construction has dditional advantage that plenty of room is available to rporate a simple electrostatic beam deflector such as that n in Fig. 1. A pair of plates 12 deflects the beam after s passed through the defining aperture 13; a similar pair ates (not shown) is mounted at right-angles to deflect the beam in a direction at right-angles to the first deflexion. The maximum angle of deflexion from the optical axis is about half a degree for a total scan of half a millimetre; the aberrations of the deflectors themselves can therefore be neglected. Fig. 2 shows a photograph of the deflectors. The deflector system is mounted on a tube 14 (Fig. 1) which is screwed into a plate 15 which also carries the electrical leads from the deflector plates through a suitable vacuum seal. The spacing between opposite plates is 5·0 mm giving a sensitivity (at 30 kV) of one micron displacement of the probe across the target for an applied potential difference of one volt. This is quite convenient for conventional electronic deflexion circuits as used with cathode-ray tube displays. It is also more convenient to make small movements of the probe electrically rather than to move the specimen by mechanical means.



g. 1. General arrangement of the electron-optical system of the X-ray microanalyser

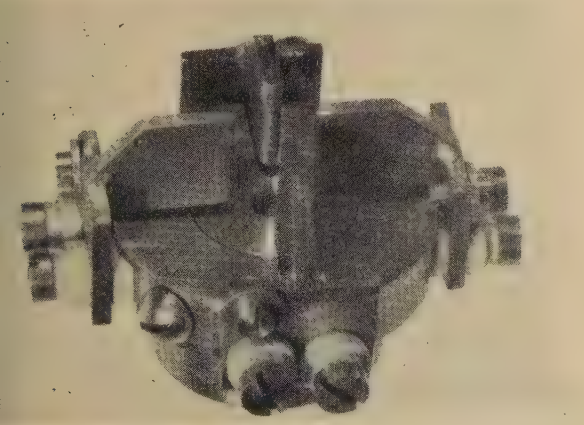


Fig. 2. The electrostatic deflector system. (Full size)

THE DISPLAY SYSTEM

Fig. 3 shows in schematic form the cathode-ray tube display. The deflector plates of the microanalyser are connected in parallel with the corresponding X- or Y-deflector plates of the cathode-ray tube so that the spot traverses the screen in synchronism with the movement of the electron probe across the specimen, whether this is scanned in a complete raster by the time bases or manually with the aid of a potentiometer, as in carrying out a point analysis, for example. The normal magnification on the screen is 600 times, enabling small probe movements to be carried out with some precision; different magnifications can be obtained by suitable attenuators attached to the microanalyser deflector plates.

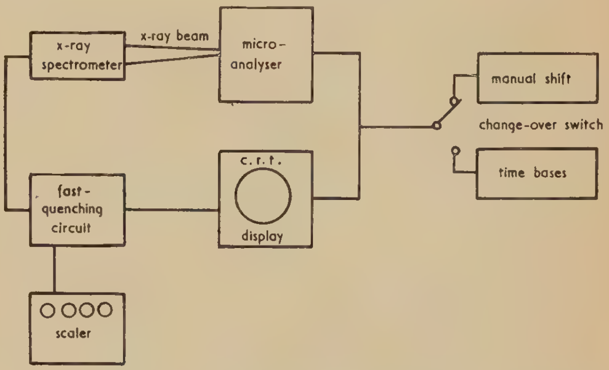
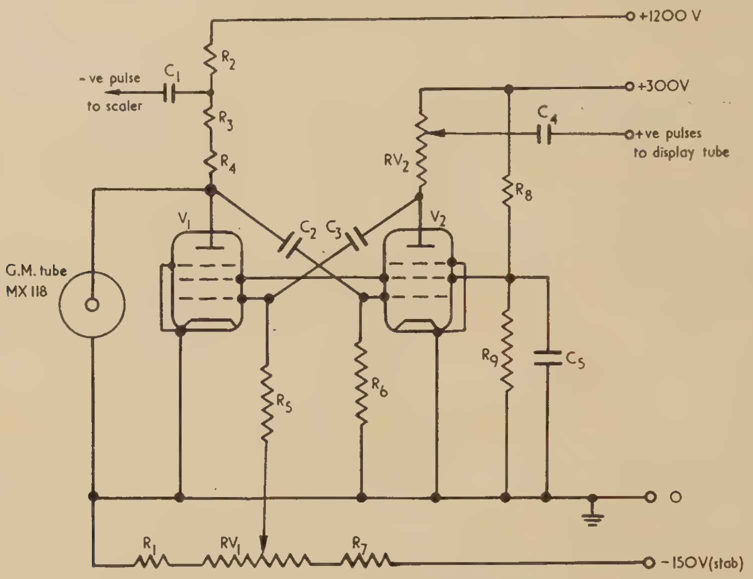


Fig. 3. Schematic arrangement of the scanning system

The intensity of the cathode-ray tube image is modulated by the electrical signal from the X-ray detector as shown in Fig. 3. By allowing the total X-ray spectrum (that is, the line spectrum and the continuous background) to reach the detector, an image of the general topography of the specimen is obtained, the details of which can be correlated with the image seen in the optical microscope. A more useful image for spectro-chemical analysis is obtained by using the spectrometer to select a particular spectral line, for example, the Cu–Kα, and causing the signal to modulate the display tube. An image is then obtained of the distribution of that chosen element in the specimen, as has been shown for example by Melford and Duncumb.(10)

MODULATION CIRCUIT

The cathode-ray tube is modulated by the output pulses of the Geiger counter. In the present spectrometer, the fast-quenching circuit of McKeown and Ubbelohde(11) is used to increase the maximum counting rate of the Geiger counter to about 10 000 per second. The circuit, with minor modifications shown in Fig. 4, consists of a monostable multivibrator which reduces the "dead time" to about 30 μs by removing the counter voltage on the arrival of a photon in the counter, thus preventing the slow drift of positive ions to the cathode. Negative pulses of about 10 V amplitude are provided to operate a scaler by tapping the anode resistor of V_1. Large positive pulses of about 60 V amplitude are available in the anode circuit of V_2; these are used to modulate the display tube directly as shown in Fig. 5, which also shows the general arrangement of the tube controls. The tube itself is the type CV966 with a long persistence screen (approximately ½ min).



R_1 = 470 Ω
R_2 = 1 kΩ
R_3 = 47 kΩ
R_4 = 47 kΩ
R_5 = 39 kΩ
R_6 = 33 kΩ
R_7 = 22 kΩ
R_8 = 10 kΩ
R_9 = 22 kΩ

RV_1 = 5 kΩ
RV_2 = 20 kΩ

C_1 = 33 pF
C_2 = 25 pF
C_3 = 150 pF
C_4 = 1000 pF
C_5 = 8 μF

V_1 = 6F12
V_2 = 6F12

GM = MX118 (Mullard)

Fig. 4. Fast-quenching circuit and modulation-pulse generator

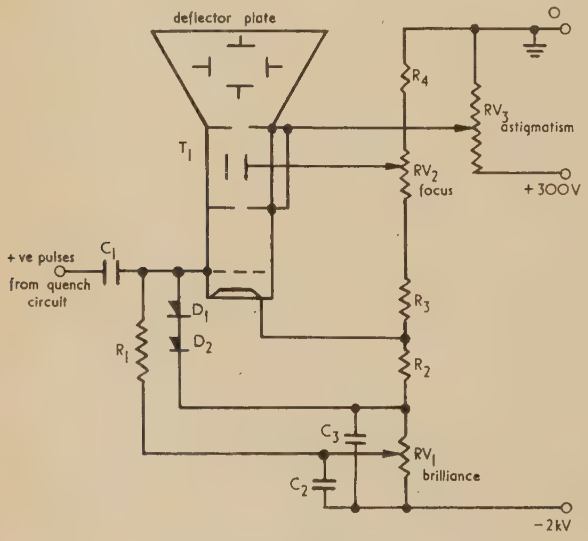


Fig. 5. Modulation and focusing controls

R_1 = 1 MΩ
R_2 = 10 kΩ
R_3 = 270 kΩ
R_4 = 3 × 470 kΩ

RV_1 = 100 kΩ
RV_2 = 250 kΩ
RV_3 = 100 kΩ

C_1 = 470 pF
C_2 = 0·25 μF
C_3 = 0·25 μF

D_1 = CG10E
D_2 = CG10E

T_1 = CV966

TIME-BASE CIRCUITS

The build-up of information on the cathode-ray tub slow compared with normal television practice for rea that are discussed below. In the present instrument, the frequency is 50 c/s and the frame frequency 0·5 c/s. F shows the line time-base circuit. The line scan is synchron with the a.c. mains by means of a simple neon-tube ci V_1 to avoid mains pick-up difficulties. The deflecting form is generated by a Miller transitron circuit V_4 wit cathode follower V_{2B} to ensure rapid fly-back, and al provide a low-impedance output circuit. Catching di V_{3A}, V_{3B} limit the maximum and minimum excursion o scan. Push-pull output is obtained by using a para amplifier V_5 to invert the scan. A potentiometer R used to balance the time-base waveform to avoid distor in the display tube. The frame time-base circuit is sin except that it is free-running, the synchronizing circuit b omitted.

In operation it is important that the mean potentia each pair of deflector plates should be the same, other astigmatism(12) might be introduced into the electron pr This is achieved by adjusting RV_5 on both line and fr timebases. In the present equipment a mean potentia about 150 V is employed; it is desirable that the differ of mean potential between pairs of plates does not ex one or two volts.

Similar considerations apply to the manual probe- control shown in Fig. 7. A double-pole two-way swit enables a pair of deflector plates to be controlled by a ga potentiometer P, giving a balanced direct-deflexion vol The pre-set resistor RV_3 is set so that the mean potenti each pair of plates is the same for manual as for electr scanning operation.

RESULTS

The scanning method is particularly useful for obtai a preliminary qualitative analysis of complex specim especially when the general distribution of the constitu exhibits marked variations. A case in point occurred du the analysis of a spark-hardened layer(13) formed on

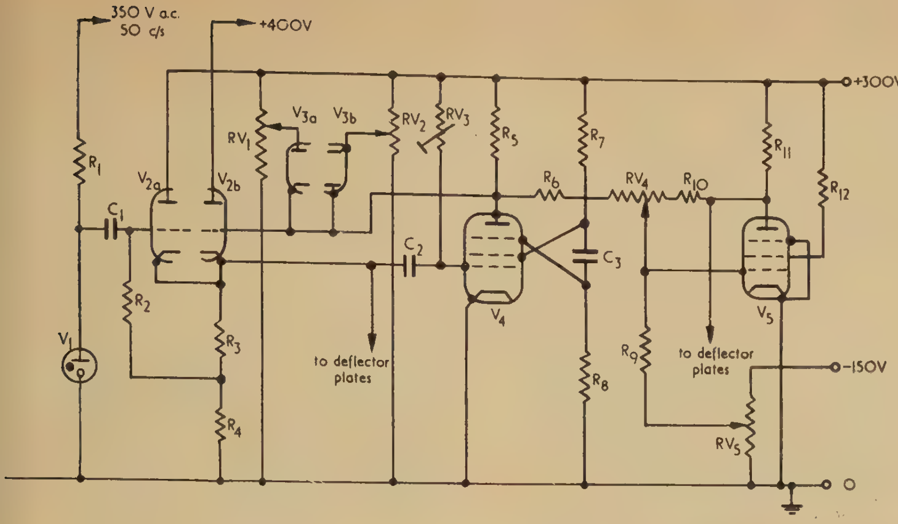

350 V a.c.
50 c/s
+400V
+300V
-150V
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
RV1
RV2
RV3
RV4
RV5
V1
V2a
V2b
V3a
V3b
V4
V5
C1
C2
C3
to deflector plates
to deflector plates

Fig. 6. Line time base

R_1 = 350 kΩ
R_2 = 47 kΩ
R_3 = 2·2 kΩ
R_4 = 33 kΩ
R_5 = 100 kΩ
R_6 = 1 MΩ
R_7 = 27 kΩ
R_8 = 27 kΩ
R_9 = 470 kΩ
R_{10} = 1 MΩ
R_{11} = 47 kΩ
R_{12} = 22 kΩ

RV_1 = 50 kΩ
RV_2 = 50 kΩ
RV_3 = 1 MΩ
RV_4 = 500 kΩ
RV_5 = 100 kΩ

C_1 = 500 pF
C_2 = 0·05 μF
C_3 = 0·01 μF

V_1 = GD86W
V_2 = 12AT7
V_3 = 6D2
V_4 = 6F12
V_5 = 6F12

Note.—Frame time base similar except $C_2 = 4\,\mu$F and $C_3 = 1\,\mu$F.

ace of a steel pin. The specimen was submitted by Dr. C. Welsh of this Laboratory. Fig. 8(*a*) is an optical rograph of a section through such a specimen; the lened layer appears as a bright band some 30 μ wide. area to the right of the layer is the unhardened steel, the area to the left is a layer of nickel which was plated o the specimen to preserve the edge of the layer during shing. The dark square, some 130 μ × 130 μ, is the that has been scanned electronically; by prolonging the osure, a thin layer of carbon contamination[(14)] can be t up which serves as a useful indicator for subsequent erence. Fig. 8(*b*) shows the corresponding scanning ige, photographed on the face of the cathode-ray tube, wing the distribution of iron in the specimen obtained by ing the spectrometer to the Fe–Kα line. The bright a on the right corresponding to the unhardened steel tains about 98% of iron; the concentration falls off idly in the layer itself; the minimum value appearing in . 8(*b*) is about 10%. Corresponding areas in the two crographs can easily be recognized. The distribution of er elements, such as tungsten, cobalt and titanium, were ained in the same way. It is hoped to publish details of investigation elsewhere.

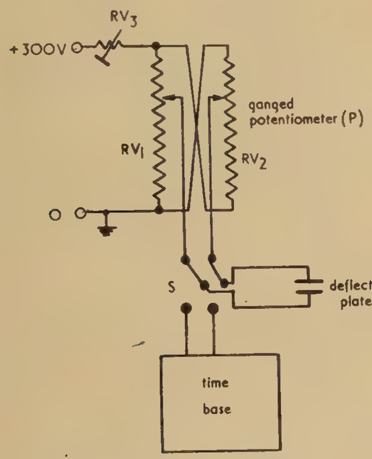

RV3
+300V
ganged potentiometer (P)
RV1
RV2
0
S
deflector plates
time base

Fig. 7. Arrangement of manual control system

RV_1 = 100 kΩ RV_2 = 100 kΩ RV_3 = 10 kΩ

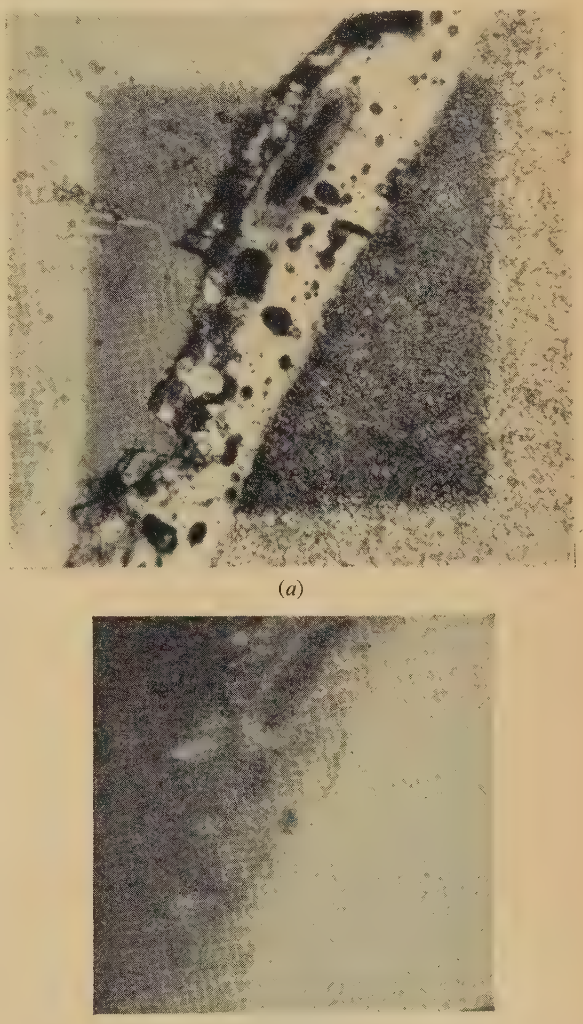


Fig. 8. (*a*) Optical micrograph (×400) of a spark-hardened steel showing area scanned (dark square 130 × 130 μ). (*b*) Electronic scanning picture (×400) using Fe–Kα radiation showing distribution of iron in the specimen

To obtain quantitative results, a point analysis must be made in selected areas. This can be carried out by switching off the scanning generators and making use of the optical microscope to position the specimen under the probe. Alternatively, the probe can be moved electrically using the image on the long-persistence screen as a guide. The second method is quicker but care must be taken to see that the movement of the probe does not affect the alinement of the X-ray spectrometer, particularly where a quartz crystal is employed.

INTERPRETATION OF THE ELECTRONIC IMAGE

In some especially favourable cases—for example, when dealing with large concentrations of a heavy element in a light matrix—no difficulty arises in interpreting the scanned image. In general, however, care has to be exercised for the following reasons. When a specimen is bombarded by electrons, two distinct radiations are produced as shown in Fig. 9, namely the characteristic line spectrum associated with the K or L shells of the atom and the unwanted white radiation (*Bremsstrahlung*) which forms a continuous background signal, which may be comparable with the wanted signal for elements present in low concentrations.

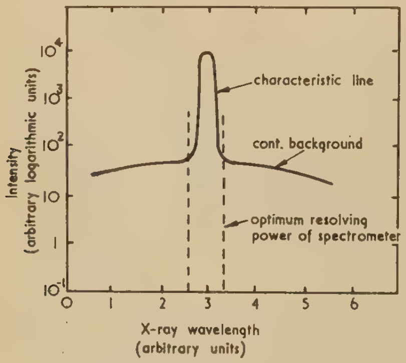


Fig. 9. Characteristic line spectrum and continuous background

This point is illustrated in Fig. 10 which shows an electron-scanning micrograph of some copper-bismuth crystals in a matrix of bismuth. The Cu–Kα line output from the spectrometer was used to modulate the cathode-ray tube, and the copper-rich crystals are delineated with a resolution of better than one micron. The exposure was continued for a sufficie time to eliminate statistical variations of contrast in t image of the crystals not associated with changes in co position. The bismuth matrix appears as a dark, but n black, background because the spectrometer cannot d tinguish between the Cu–Kα line and that part of the co tinuous spectrum of bismuth of the same wavelength. It not possible to say from a picture of this type whether not a small amount of copper is present in the bismuth. T background can be reduced but not entirely eliminated increasing the resolving power of the spectrometer. Th difficulty is overcome in point analysis by subtracting t background from the total count recorded. This cannot done easily with a cathode-ray-tube display, so allowan should be made in interpreting the image. It is advisab to check at several places by point analysis; this assists great in the interpretation of the scanned image on the display tub

Fig. 10. Electron scanning picture of copper-bismuth crystals in bismuth matrix. Spectrometer set to Cu–Kα line (×400)

STATISTICAL VARIATIONS OF CONTRAST

The output pulses from the X-ray detector occur random, and cause a random modulation of the cathode-r tube. Each pulse is registered as a flash of light from t fluorescent screen or as a bright dot in the photograp Consequently the image of a specimen of uniform composit will exhibit random variations of contrast if insufficient pu are available. A similar problem is encountered in electro microscope images.(15) If N random pulses are associat with each picture element then variations of contrast occur, whose root mean square is $N^{-1/2}$. These spurio variations must not obscure the variations of contrast aris from changes in the composition of the specimen. Rose has investigated the problem experimentally and conclu that the eye cannot distinguish real changes of contrast fro random ones unless the r.m.s. fluctuation is less than one-fi of the mean contrast; that is, a minimum signal-to-noise rat of five is required.

The exposure time required to reduce these rando variations below a fractional amount P is given by:

$$t = \frac{n^2}{P^2 RC} \qquad ($$

where n^2 is the number of picture elements, R is the countin rate from the pure element ($Rt = Nn^2$) and C is the fraction concentration of the wanted element in the specimen. F example, with 10^4 picture elements, C equals 0·1 an R equal 10^4 counts/s. Thus t equals 250 s for the require P value of $\frac{1}{5}$.

Conversely, equation (1) can be used to find the maximu number of picture elements for a given exposure tim Equation (1) shows that the exposure time is greatly influence by the number of resolved points in the image and th maximum random variation in contrast that can be tolerate

As a practical illustration, Fig. 11 shows a series electron-scanning pictures of the distribution of chromiu in a 9·5% chromium cast iron, photographed for 30, 60, 1 and 240 s respectively, the camera being suitably stoppe down for the different exposures. Bright areas correspon to C equal to 25% of chromium, R equal to 6000 counts and n^2 equal to 10^4 picure elements. From equation (t equals 166 s. This is in qualitative agreement with th images of Fig. 11(*c*) (120 s) in which "graininess" is noticeab but not troublesome and Fig. 11(*d*) (240 s) in which th resolution (1–2 microns) approaches that obtainable in th static probe.

The dark areas in Fig. 11 correspond to a uniform co ation C of 5% of chromium. Here t equals 830 s; for reason Fig. 11(*d*) (240 s) exhibits marked "graininess" in regions.

TIMUM PROBE SIZE FOR "GRAINY" IMAGES

practice, time does not permit the conditions of tion (1) to be satisfied except for the photography of ially selected areas. For visual work a long-persistence n of fixed time constant (approximately 30 s) is con- ent. The image is then similar to that of Fig. 11(*a*) or) in which the resolution is limited by random fluctuations. ler these conditions, the overall resolution can be im- ved by increasing the probe size. This can be done lily by weakening the first de-magnifying lens. The ltant increase in probe current and counting rate R will ice the random fluctuations. The permissible increase robe size may be calculated approximately as follows: it is supposed that the exposure time is reduced from t , so that a grainy picture results, the resolution will now vorse and will be given by:

$$d_g = d\sqrt{\frac{t}{t_g}} \qquad (2)$$

re d is the resolution in the absence of random effects. reason for this is that the minimum detectable-picture ent is increased by a factor t/t_g in area.

making the probe diameter equal to $d(t/t_g)^{1/4}$, the two lution limits are equalized and the resolution improved. example may clarify this. If, with the data of Fig. 11, exposure time is reduced from t_{min} of 166 s to t_g of 30 s, ainy picture results in which the fine details cannot be nguished from the statistical "graininess". Equation (2) gives the loss in resolution as a factor of 2·4—for example, from 1–2 μ in a grain-free picture to 5 μ—in qualitative agreement with Figs. 11(*d*) and 11(*a*) respectively. By the increase of the probe diameter by a factor of $(166/30)^{1/4}$, that is, 1·5, the overall resolution should be improved to 2–3 microns.

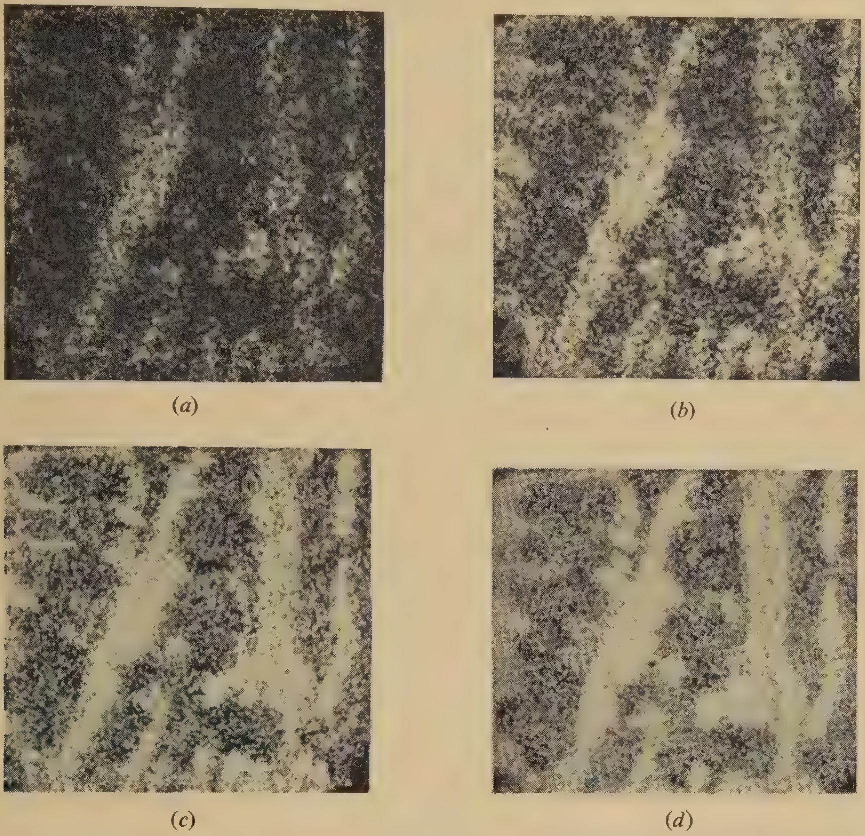

(*a*) (*b*) (*c*) (*d*)

Fig. 11. Effect of random variations (statistical "graininess") on electron-scanning pictures of the distribution of chromium in cast iron (×500): (*a*) 30 s; (*b*) 60 s; (*c*) 120 s; (*d*) 240 s. Bright areas, 25% Cr; dark areas, 5% Cr

ACKNOWLEDGEMENTS

The authors wish to thank Mr. E. Pesterfield for the mechanical design and construction of the deflector-plate system, their colleagues in the laboratory for helpful discussion, and Dr. T. E. Allibone, Director of the Research Laboratory, Associated Electrical Industries, for permission to publish this paper.

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Design for an autographically recording tensile machine

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An improved "hard" type tensile machine is described, designed primarily for metallurgical usage. Compactness and mechanical simplicity are combined with maximum accessibility of the load measuring device and specimen, and the load is measured with an electro-mechanical dynamometer which is easily adapted into a system for autographically recording the load-elongation curve. The machine should be particularly useful for dry-box or hot-cell work.

INTRODUCTION

Various designs have been proposed for machines to measure the load-extension relationship of materials strained in tension.(1–3) Of these, the one which has been most used in metallurgical research is the "hard" type tensile machine described by Polanyi.(3) The principle of such a machine is shown in Fig. 1. By turning the nut *N*, the screw *S* is moved downwards so that a load is applied to the specimen *Sp*, the magnitude of which is given by the deflexion of the elastic beam *B*, held on the rigid framework *F*. The beam dimensions are chosen so that the deflexion (usually measured with an optical lever system) is small over the working load range, and the machine is then capable of registering small rapid load relaxations, a necessity if true load-elongation relations are to be obtained from materials showing yield points or jerky-flow. With "soft" machines, those in which the load-measuring device is a soft spring, rapid load variations are not recorded because the extensions required are too large, whilst in dead loading machines no load relaxations are possible. In both these types of machine sudden yielding will show as merely an extension under constant load, and it is possible to confuse yield point effects with easy-glide.

The design shown in Fig. 1 is simple and effective but suffers from the disadvantage that tests can only be made conveniently at ambient temperature due to the difficulty of enclosing the specimen in a temperature bath. Improvements in the design have been mainly concerned with overcoming this difficulty.(4,5) In the design to be described here provision is made for easily changing the testing temperature while still retaining compactness and mechanical simplicity and e access to the load measuring device. Furthermore, electro-mechanical dynamometer has been employed measure load in place of the conventional beam and opti lever system, thus allowing a simple means of autographica recording load-elongation curves.

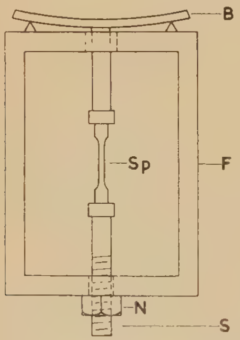

Fig. 1. Schematic diagram of a simple Polanyi tensile machine

DESCRIPTION OF THE MACHINE

General features. A photograph of the machine is sho in Fig. 2(*a*) and a diagram in Fig. 2(*b*). The main work parts are:

(1) A rigid framework consisting of two heavy rectangu steel plates P and P_1, held together by two para ground-finished steel bars B and B_1.
(2) A lead-screw L, held centrally in the framework.
(3) A cross-head C, carried on the lead-screw, and guid on the frame so that it is constrained to move alon straight line.
(4) Tie rods T and T_1, attached to the cross-head a running through clearance holes in the plate P_1 to connecting cross-piece X, which carries the botto specimen grip G_1.
(5) A dynamometer D, held in a mounting Z on the t frame plate P.
(6) A tie rod Y, running from the dynamometer, through central hole in the lead-screw, to the top specim grip G.

Details of the lead-screw. The lead-screw has accurately cut right-hand thread on its outer surface, central hole along its complete length, and is held at bo ends in thrust bearings K and K_1 mounted in the inner fac of the plates P and P_1. Two nuts H and I at either end of t screw are tightened against each other to eliminate lon tudinal play whilst allowing rotational freedom. At the t end the screw carries a worm wheel W (locked in positi by the back-nut J) which is used to transmit power to t screw from a drive shaft F and worm. The shaft runs in b races housed on the under surface of the top frame pla and can be driven by hand, or more conveniently, through chain and sprockets, from an electric motor as shown Fig. 2(*a*).

Details of the cross-head. Kinematical principles are us in the design of the cross-head. The minimum number constraints to allow the required one degree of freedom a ided by the mating of the threads of the cross-head with e of the lead-screw, and by the contact of a brass-lined g E on the cross-head with the right-hand bar of the framework. Strictly speaking the latter contact should point one but in fact a short line contact is used to ce wear. A brass block M, loaded by compressed spring ers R and R_1, maintains the contact, and to compensate he frictional drag at the contact a pair of brass blocks d O are included at the left-hand side of the cross-head. e are a sliding fit inside four prongs on the cross-head, are loaded against the left-hand frame post by compressed g washers R_2 and R_3. With the bearing surfaces and unt of loading on both frame posts the same, this arrange- t eliminates twisting effects from the moving cross-head out constraining the latter from following its guide.

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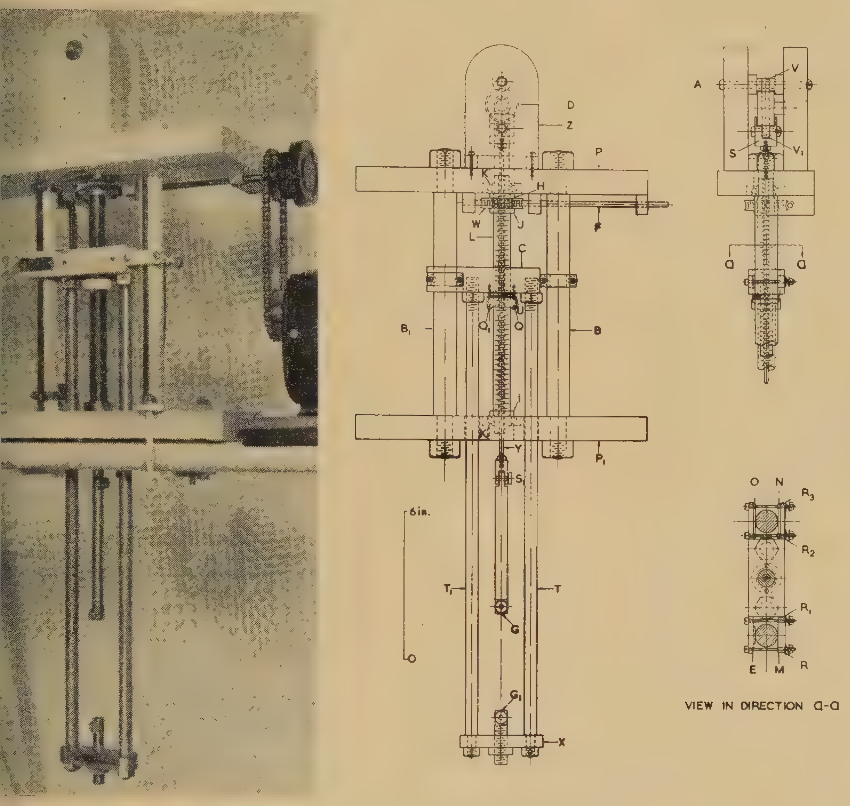
* Now at Materials Research Corporation, Yonkers, New York, U.S.A.



(*a*) (*b*)

Fig. 2. (*a*) Photograph, and (*b*) diagram of the tensile machine

inally, a spring washer is used to eliminate back-lash veen the cross-head and lead-screw. The washer is pressed by the nut U which is prevented from unscrewing he two pins Q and Q_1 fitting into clearance holes in the s-head.

etails of the dynamometer and its mounting. The load is sured with a commercial dynamometer,* the design of h is based upon the mechanical proving ring. The ring, hined from beryllium-copper, has lugs at each end to h shackles can be attached. The top lug V is carried high tensile steel bolt A held between the two sides of achined steel block Z screwed to the top plate P of the e, and hanging from the bottom lug V_1 is a freely swinging shackle S and the tie rod Y which runs through the lead screw. At the bottom end the tie rod is screwed into a round bar carrying the top specimen grip, a pinned tongue and slot joint S_1 at the centre of the bar, allowing freedom of movement in a plane at right angles to that in which the shackle can move. This flexibility in two planes assists in the achievement of axial loading in the specimen. The various members of the assembly are carefully alined before the top lug of the dynamometer is clamped in position.

THE MEASUREMENT OF LOAD AND ELONGATION

The method of using the dynamometer. Four strain-gauges, arranged in a closed bridge circuit, are bonded to the inner surface of the proving ring which is sealed in a die-cast case. When the bridge is activated from a constant a.c. or d.c. source the output voltage, with no load applied to the ring, is small and constant, and of a value determined by the matching of the resistances in the four arms of the bridge. If the ring is loaded it becomes elastically deformed, causing a change in the resistance of each strain-gauge (one opposite pair of gauges increasing in resistance and the other pair decreasing) and a change in output proportional to the applied load.

Various arrangements are possible for activating the dynamometer and for measuring the output voltage, the choice depending on a compromise between accuracy and speed of response. The comparative ease with which the activating and recording system may be changed to meet the requirements of a particular type of test is an important advantage of using a dynamometer. A simple system is described below which is capable of accurately recording load variations up to the frequency that is normally observed during repeated strain-ageing.

Three 6 V high capacity lead accumulators are connected in series with a variable dropping resistor (made up of stable decade resistance boxes; smallest value 0·1 Ω), and the strain-gauge bridge, the output from the bridge being fed directly into a Honeywell–Brown "Electronik" potentiometric recorder (model no. 153 × 17V − X − 30A4R). The recorder is modified to cover a range of −5 to +50 mV in 10 mV overlapping steps, 1 in. on the chart corresponding to 1 mV, and has a response time of 2½ s for the full-scale deflexion of 10 in.

The dynamometers are manufactured in various sizes to cover a series of load ranges, and the performance depends to some extent on the size. In the present machine a 0 to 300 lb dynamometer has been used which at the maximum permissible continuous input voltage of 18 V delivers about 75 mV for full load. The recording chart can be read easily to the nearest 1/40 in. so that under the limiting operating conditions the load can be determined to the nearest 1/10 lb.

Since a test is liable to last for several hours it is important

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Manufactured by J. Langham Thompson Ltd., Springfield oratories, Bushey Heath, Herts.

to ensure stability of the activating voltage and of the dynamometer for periods of this order. After a preliminary discharge for a day or two the voltage of the accumulators drops only slowly (about 1% per day) with time over a relatively long period; if in this steady range the input voltage is accurately set before a test, the changes during the test become negligible.

Regarding the dynamometer two effects must be considered: the effect of temperature on the resistance of the wire forming the strain-gauges and the effect of temperature in causing strain in the proving ring. The gauges are guaranteed as having very small temperature coefficients from −40 to +100° C and no instability in their resistance characteristics has been observed with the changes of temperature that occur in an average laboratory. Temperature instability of the proving ring has been found a little more troublesome, a change of 10° C resulting in a zero shift of about 1/20 mV. The normal fluctuations of ambient temperature over a period of a few hours are unlikely to produce appreciable errors, but if the specimen is held in a temperature bath it may be necessary to insulate the dynamometer. Alternatively, the dynamometer may be allowed to reach its equilibrium temperature before starting the test, providing this temperature is not too high. It is advisable to activate the dynamometer continuously to avoid the warming up period due to the local heating by the exciting current in the gauges.

Calibration of the machine is best effected by hanging weights from the top specimen grip. With the dynamometer described above the load millivolt relationship was linear to within $\frac{1}{2}$% across the complete load range, and the hysteresis between loading and unloading was immeasurably small. The machine is calibrated before each test by attaching a standard weight, and altering the dropping resistance in the input circuit until the required output is obtained.

The measurement of elongation. The elongation of the specimen is measured from the movement of the cross-head after a suitable calibration to allow for the small elastic deflexion (about 0·025 in. at full load) of the machine members and dynamometer under load. With constant speed motors driving the machine and recorder chart, accurate gears, and an accurate lead-screw thread, the cross-head movement can be estimated from the recorder ch directly so that the machine becomes fully autograp recording load and elongation simultaneously. The accur of the elongation measurement will then be determined the limits set on the accuracy of the motor speed, lead-sc and gears. Alternatively, the cross-head movement can measured directly with a dial gauge and the data correla with the load measurements from the recorder chart.

APPLICATION OF THE MACHINE TO DRY-BOX OR HOT-CELL USAGE

Because it is compact and can record the load-elongat curve remotely the new tensile machine should lend it readily to dry-box or hot-cell usage. Thus, for test specimens of high activity and/or toxicity the comp machine could be easily enclosed, and the dynamometer motor leads brought out to activating and recording equ ment removed from the box or cell. Several machi covering various load ranges, could be used with one se recording equipment, or alternatively a simple modificat of the dynamometer mounting could be made to al various dynamometers to be fitted into one machine remot For tests on specimens of low activity it would probably sufficient to shield only that part of the machine below bottom frame plate, since apart from the short time ta to place the specimen in the machine the operator wo not be required to remain in close proximity to the sour radiation.

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Laboratory and workshop notes

Modification of an X-ray powder camera to examine two samples simultaneously

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For many purposes, the direct comparison of Debye–Scherrer patterns from two samples, one of which may be a standard if desired, is more convenient than measuring the films and comparing tabulated data. For instance, changes in lattice parameters or line broadening may be easily detected by this means, particularly if the two patterns are produced simultaneously on one film, when no c rections will be required for errors due to specimen center or film shrinkage.

A simple modification of a Unicam 9 cm powder cam has been made that enables two samples to be exami simultaneously when required. Fig. 1 shows the patte from magnetite ($a_0 = 8\cdot395$ Å) and gamma ferric ox ($a_0 = 8\cdot35$ Å), obtained with the modified camera.

The modification, shown schematically in Fig. 2(*a*), and plan is Fig. 2(*b*), is as follows. The camera is divided upper and lower chambers by a horizontal partition, c sisting of two sectors of hard brass sheet 9 cm in diame and approximately 1 mm (20 s.w.g.) thick, mounted centr in the film aperture. The two sectors are fixed in four s

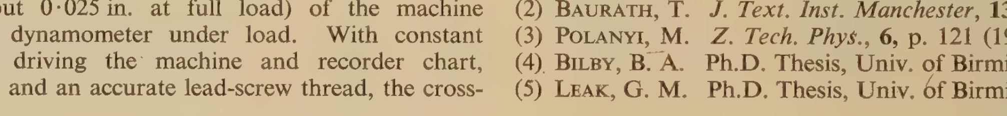
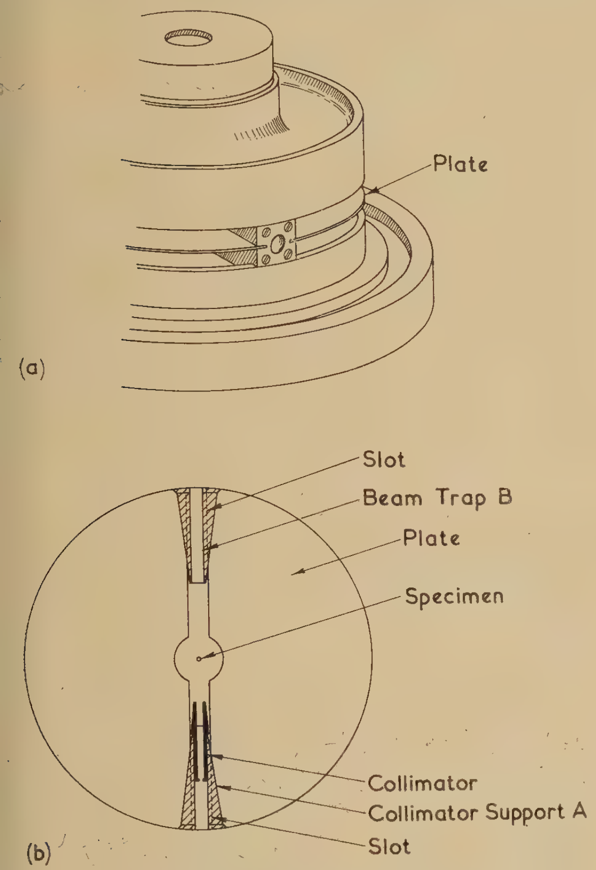


Fig. 1. X-ray diffractograms from magnetite ($a_0 = 8\cdot395$ Å) (top) and gamma ferric oxide ($a_0 = 8\cdot35$ Å) obtained with the modified camera

in the sides of the collimator support *A* and beam trap *B*. making the slots just wide enough for the plates to be a 1 fit in them no other fixing was found to be necessary, Araldite or a similar cement could have been used if iired.

he two samples are both loaded into a single silica illary tube, being separated by a plug consisting of a rt (1 mm) length of silica rod as in Fig. 3; the composite cimen is so mounted in the camera that one sample is ow the partition and the other above. In this way, the racted beams from each sample are recorded separately simultaneously and therefore under identical conditions. capillaries are supplied by the Thermal Syndicate Ltd.



ig. 2. (*a*) General arrangement of modified camera, and (*b*) plan view, showing position of dividing plate

l have a bore of 0·15 to 0·25 mm and wall thickness of 2 to 0·035 mm. The plugs are made from silica rod wn down to approximately the same diameter as the bore the tube. The operation of filling the samples into the e may be conveniently carried out under a medium wered (X30) stereoscopic microscope, using two simple ls made of stiff wire; one of diameter slightly less than t of the capillary and the other $\frac{1}{3}$ to $\frac{1}{2}$ its diameter. ese are used alternately, the former to press a little at a e of the powdered sample into the capillary, the latter to np it down. The compressed powders are located by plugs ilica rod and both ends of the capillary sealed with Canada sam in xylene. The outside of the capillary can be cleaned rolling with the finger across a piece of paper laid on a d flat surface. The completed arrangement is illustrated grammatically in Fig. 3.

If it is found that one of the samples requires a longer exposure than the other, then the specimen may be shifted axially to bring part of the plug into the primary X-ray beam so that the volume of the other sample irradiated is reduced.

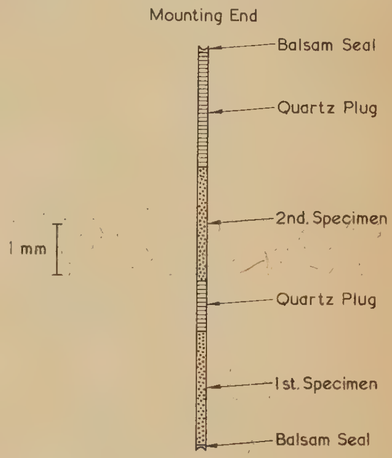


Fig. 3. Composite specimen mounted in a silica capillary tube

The height of the collimated beam can be increased if necessary, by enlarging the bore of the cylindrical section of the collimator, first springing open the scatter slits to admit a twist drill of the necessary diameter. Care should be taken not to pass the drill right through the collimator. The scatter slits are then bent back to their original position. By this method the height of the 2·0 × 0·5 mm collimator can be increased to 2·75 mm.

The effect of this modification is to obscure the equatorial region of the diffraction pattern, which theoretically involves some loss of resolution, since the "umbrella effect" increases the breadth of lines above and below the equator of the film. In practice, for the comparison of two samples, this is more than counterbalanced by the elimination of the variation in instrumental errors that occurs when two specimens are photographed in succession. The effective radius of the camera is also slightly increased for non-equatorial rays, but this is not significant for comparative purposes.

The camera can still be used for single samples after modification, when the extra time required for the special specimen preparation is not justified; it has been found that the horizontal gap in the diffractogram is not inconvenient in practice. The only disadvantage of the modification is that to change the collimator it is necessary to remove the top plate of the camera.

Our thanks are due to Mr. W. Conn of the Laboratory workshop staff, who carried out the modification and to Dr. J. S. Forrest, Director of Laboratories, for permission to publish this note.

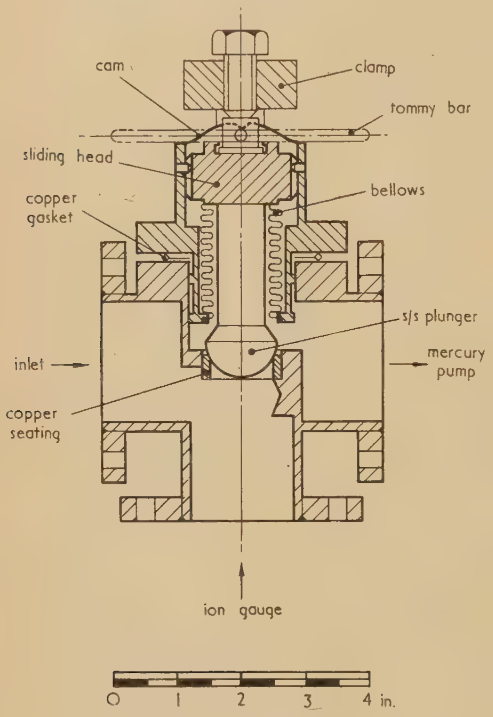
All-metal high-conductance vacuum tap

By A. Crocker, Services Electronic Research Laboratory, Baldock, Herts

[*Note received* 22 *June*, 1959]

For some high-power microwave tubes(1) the minimum time for vacuum processing has been about ten days—from sealing on the pump to squeezing off. This time includes baking before and after activation of the cathode, and leak checking. There are several reasons which suggest the need for a reliable method of isolating the tube from the pump and traps during this time. The order of vacuum required during shut off is 10^{-6} mb or less. A bakeable high-conductance tap has therefore been designed to give this and to have a conductance, fully open, of 8 to 9 l./s, variable from shut-off. The type of seal developed by Alpert,(2) using a highly polished Kovar cone on a diaphragm forced into a soft copper block, has been modified to a polished stainless-steel spherical plunger forced *via* bellows into a soft copper annulus.

The figure shows the essential details of the tap. It comprises two main parts: the body machined from stainless-steel bar, and the replaceable plunger mechanism also in stainless steel. The body is nickel plated at the site of the copper annulus and the latter is hydrogen brazed (or, better still, vacuum brazed) into the body with copper–silver eutectic. The plunger mechanism is a slide fitted into the body, and sealed with a diamond-section copper gasket clamped with eight $\frac{1}{4}$ in. stainless-steel bolts. This gives a good thermal-expansion match for the seal at elevated temperatures. The plunger movement is transmitted from a sliding head in the mechanism housing. A stainless-steel bellows, 0·008 in. wall thickness, is brazed between the sliding head and the housing, allowing nearly $\frac{3}{8}$ in. traverse for the plunger. All parts are nickel plated at the surfaces to be brazed. Movement of the sliding head is controlled by a tommy bar rotating over a cam surface on the slide housing. The tap is shut more firmly by a removable, hardened-steel clamp which bridges the plunger mechanism to avoid strain on the copper gask
The seating for the plunger in the copper annulus is ma
when the tap is closed for the first time and thereafte
torque of about 30 ft lb on the clamp screw is sufficient
reduce leakage to less than 10^{-7} l. mb/s.



Schematic view of tap

The body has two inlet ports at right-angles, either of wh
can be used for pumping, with the spare available for an i
gauge or omegatron. All ports are welded with simi
flanges, sealed with diamond-section copper gaskets and h
with $\frac{1}{4}$ in. stainless-steel bolts. The tap is designed to
directly on to the S.E.R.L. design of conductance-coo
liquid-air trap (Elliott Brothers B597).

Models of this tap have been in continuous satisfactory
for about two years. They have been mounted external
the baking oven, but degassed at 250° C or more by clos
wound heater tapes, the moving parts being lubricated w
molybdenum disulphide.

For other reasons, this tap is intended to be an integ
part of the pumping system and no tube has yet been remov
from the pump with a tap attached. Some advantage mi
be gained on high-power tubes by sealing-off with the t
so that the valve can be removed and aged on a modulat
It may then be repumped before finally squeezing off.

The design of the ports can be modified to make a comp
tap suitable for this purpose, with negligable loss of c
ductance. A paper to be written later will deal fully w
the complete vacuum system for processing high-pow
valves.

Permission of the Admiralty for publication of this no
gratefully acknowledged. The author is also indebted
S.E.R.L. Drawing Office for work on the design of this ta

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mi-automatic control system for producing constant cooling rates

L. W. PHIPPS, B.Sc., A.R.C.S., A.Inst.P., Physics Department, The National Institute for Research in Dairying, University of Reading, Berks.

[*Paper received* 24 *March*, 1959]

This control system was designed and is best suited for cooling, at a constant rate, the metal sample block of a differential thermal analysis apparatus used for studying supercooling, melting and solidification phenomena in organic materials. An automatically-controlled flow of liquid refrigerant, passing through a simple heat exchanger, is used to cool the primary liquid circulating continuously in the coil system of the block. The apparatus is also suitable for uniform cooling of a small water or oil bath. For either application, controlled cooling rates of up to about 2° C/min are attainable. Using refrigerated water, control is possible from 95 down to about 10° C depending on the rate, but the range could be extended to lower temperatures by the choice of suitable liquid coolants.

omprehensive survey of the theory and applications of
rential thermal analysis has recently been published by
thers and Chiang.(1) The principle of this form of
ysis is simultaneously to heat, or cool, the material to
xamined and an inert reference substance in the same
osure. The differential thermal curve is then formed by
rding the temperature difference between the two sub-
ces as a function of time or of the temperature of the test
rial; the presence of peaks on these curves indicates the
urrence of phase transitions. A great variety of materials
different types of transition are amenable to examination
his method. On the whole, the differential heating curve,
er than the cooling curve, has proved more useful, and
eat number of control devices for producing uniform
ing have been described. There are some situations,
ever, where the substance needs to be examined during
ing. This can be the case, for example, when studying
tallization phenomena and the reversibility of transitions
reactions. Further, for quantitative work constant
ing rates are required.

common practice for obtaining regulated cooling is to
advantage of the natural cooling tendencies of the
em and partially balance this by a controlled heat input.
eful consideration has then to be given to the thermal
acity of the sample holder or furnace in relation to the
ing rates required. Wilburn(2) and Lomas and Finch(3)
rolled the natural cooling of their furnaces. In the differ-
al thermal analysis apparatus of Penther, Abrams and
ss,(4) air fans were introduced to provide forced convec-
cooling of the sample block. This permitted greater
ing rates than would otherwise have been possible and
nded the lower temperature limit of the range over which
rol was maintained. An ingenious arrangement which
a different principle has also been devised.(5) This
luced uniform heating or cooling of a sample by passing
rough a heavy-walled metal tube along which a constant
perature gradient was established. Generally speaking,
need in these cases was for continuous thermal analysis
a wide temperature range and some hundreds of degrees
ve room temperature. None of the arrangements is
icularly suitable for use around room temperature.

he purpose of this paper is to describe a rather different
nod of obtaining closely controlled linear cooling,
loying a liquid coolant system. The apparatus is capable
ooling an aluminium block, containing the inert and test
tances for analysis, at low constant rates (up to approxi-
ely 2° C/min) from 95 to about 10° C depending on the
rate. Water is used as the cooling liquid in this case, but the range could be extended below 0° C by the choice of suitable liquid refrigerants (e.g. ethylene glycol/water mixtures). The apparatus is also able to produce uniform cooling of a small oil or water bath for general laboratory use.

ASSEMBLY TO BE COOLED

Brief mention will be made of the assembly to be cooled. A cylindrical aluminium block (5 in. long, 4 in. diameter) holds the sample containers and is similar to that used by Cox and McGlynn(6) for studying transitions in lubricating greases. It has a thermal capacity of about 2 500 J/° C. Two wells to take the sample containers are drilled equidistant from the cylinder axis and on the same diameter. An axial hole receives the cylindrical heater. The sample holders are of brass or stainless steel with twist-on lids and rest in the aluminium block with insulating spacing pieces to prevent direct contact with it. Thin-walled stainless steel tubes, to take fine-wire copper/constantan thermocouples, pass centrally through the lids to which they are sweated. When in use, the block is suspended inside a Dewar vessel (1 gal) by means of Tufnol rods attached to the Dewar lid. Insulated in this way, practically linear heating curves up to, and somewhat beyond, 100° C can be obtained without control devices by merely applying a pre-set constant voltage to the heater. The sample block is cooled by liquid passing through coils of copper tubing ($\frac{3}{16}$ in. internal diameter) wound tightly on it. Connexion is made through the Dewar lid to a centrifugal pump and the rest of the primary circuit, to be described in the next section.

THE CONTROL SYSTEM

The principle used is one of employing a temperature difference to control a rate-of-change.(7,8) Liquid is pumped through the cooling coils of the block at a constant rate, whilst the temperature of the liquid entering the coils is regulated in such a way that the temperature difference between this and the centre of the block remains constant. Attempts to achieve control by regulating the temperature of the inflowing with respect to the outflowing liquid proved less satisfactory. Cooling of the circulating liquid is carried out in a heat exchanger through which the secondary, refrigerated, liquid flows under controlled conditions.

For constant cooling rates, a number of conditions have to be satisfied. The thermal diffusivity of the block and the primary liquid must remain substantially invariant throughout the temperature range in question. Provided the temperature coefficients of the parameters involved are not large, variations in cooling rate arising from this source are likely to be small enough to be neglected. This condition seems to be met in the present arrangement. In addition, the natural thermal leakage from the block in the absence of liquid flow must be negligible compared with the regulated cooling imposed on it, since automatic correction is not obtained for natural leakage. On the other hand, full compensation results for any small heat influx in excess of the natural losses. The temperature fall due to natural leakage from the assembly in the Dewar vessel is small (approximately 0·1° C/min at 100° C) and generally negligible with no primary liquid flowing in the coils. With liquid flowing, the thermal losses in the pipe system outside the Dewar have to be considered. Heat leakage from the liquid as it flows from the block to the heat exchanger is permissible, but only to the extent necessary to cool the block at the chosen rate. Above about 70° C the losses are great enough to prevent controlled cooling, unless this is at a high rate, but compensation for this over the temperature range in which it is significant is easily effected. The manner in which the correct balance of heat exchanges in the whole system is maintained will be clear from the following description of the apparatus.

The centrifugal pump *P* (Fig. 1) pumps liquid from the Dewar vessel reservoir *R* to the Linde type heat exchanger *H*, through the coil system of the block *B* to a piezometer *E* and its throttling valve *T* and thence back to the reservoir.

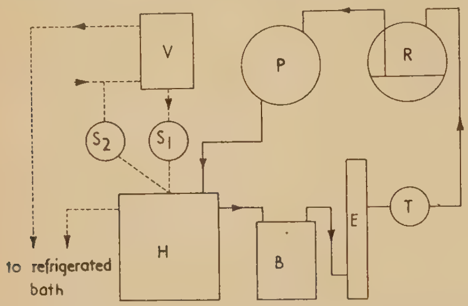


Fig. 1. Block diagram of assembly showing liquid flow routes

———— = primary circuit
– – – – – – = secondary refrigerated circuit

This primary circuit is a closed system with a capacity of about a litre. The connecting pipes are all well lagged. The heat exchanger is made of copper refrigerator tubing ($\frac{3}{16}$ in. internal diameter) which carries the primary liquid, threaded through a length (8 ft) of thick-walled Neoprene tubing ($\frac{1}{2}$ in. internal diameter). This composite tube is wound into a helix and mounted inside a well-insulated container. The annular space between the copper and Neoprene tubing provides passage for the secondary coolant. By slight throttling of the main pipe at *T*, liquid rises in the piezometer tube and its level serves as an indicator of the flow rate. A constriction at the lower end of the tube damps out fluctuations from pumping surge. As constancy of flow only is needed, the tube is uncalibrated and the level after being arbitrarily set at the beginning of an experiment is maintained by adjusting the pumping speed. Normally the only variation expected is a gradual, but overall slight, fall as the viscosity of the circulating liquid increases with fall of temperature.

The secondary liquid is contained in a well-insulated refrigerated bath; when water is used, this is conveniently kept at 2 to 5° C, the temperature not being critical. By t
action of an immersion pump this liquid passes to the elect
magnetically-operated plunger valve *V*, which also incorpora
a constant head device (see Fig. 2). Liquid passing unt
gravity through this valve then enters the heat exchang
where it cools the primary liquid and then flows back to t
bath, together with the overflow from the constant hea
The amount of heat extracted from the primary liquid
therefore determined by the quantity of refrigerant passed

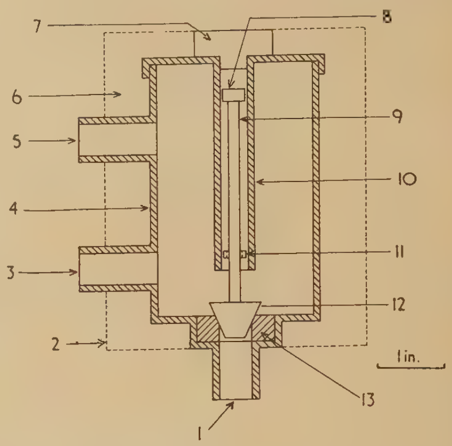


Fig. 2. Vertical section through plunger valve

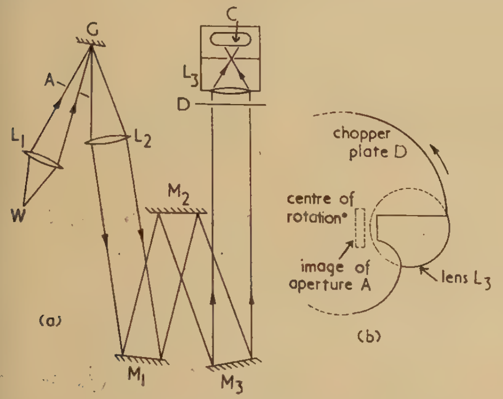
(1) outlet to heat exchanger; (2) outer casing; (3) coolant inlet
(4) cylindrical body; (5) coolant outlet; (6) thermal insulatio
(7) solenoid; (8) adjustable ferromagnetic head; (9) plunge
stem; (10) guide tube; (11) perforated spacer; (12) plunge
head; (13) rubber seating.

the plunger valve. This valve is arranged to operate
intervals of one second, the duration of each "open" peri
however, being dependent upon the temperature different
across the block and the primary liquid flowing into the co
The control of the duration of the resultant pulses of refrigera
flowing to the heat exchanger is accomplished in the follow
manner.

A copper/constantan differential thermoelement, suitab
insulated, is used to detect the temperature difference betwe
the block centre and the inflowing primary liquid. T
thermojunction for the liquid is sheathed in a thin-wall
stainless steel tube and, by means of a metal T-piece,
mounted centrally in the primary liquid stream at the po
where the pulses of refrigerant first enter the heat exchang
and make contact with the primary flow tube. In t
position, the junction detects the operation of the plung
valve with a minimum of delay.

The thermoelement is connected to a sensitive reflecti
galvanometer which is incorporated in the optical arran
ment shown in Fig. 3(*a*). Light from the source *W* (24
lamp), after passing through the limiting rectangular apert
A and being focused by lens L_1 on the galvanometer mirror
is reflected, passes through the collimating lens L_2 and the
to mirror M_1. Two more reflexions from M_2 and M_3
used to gain optical path length and concomitant sensitivi
a slightly magnified vertical image of *A* is then received by le
L_3. The light is finally incident upon the gas-filled pho
electric cell *C*. The position of *A* is a compromise such tha
reasonably sharp image is formed at L_3 but without restrict
unduly the amount of light incident on the galvanome
mirror. Lens L_2 is kept fairly close to the galvanometer
that it accepts the reflected beam for reasonable galvanome
deflexions whilst, at the same time, impairment of the mag

on factor of the optical lever is kept to a minimum. The falling on cell C operates the plunger valve through a entional amplifier-relay circuit. To control the duration ch "open" period, and hence the magnitude of the pulses frigerant to the exchanger, a light-chopping device is led at D. This consists of a thin aluminium plate ed at 1 rev/s over the face of lens L_3 by a small synnous motor. The plate is cut away in a spiral fashion to the profile shown in Fig. 3(*b*). As the light beam moves left to right across lens L_3, corresponding to a reduction he temperature differential, the photoelectric cell is inated (and the valve open) for increasing fractions of second.



. 3. (*a*) The optical system. (*b*) The light beam chopper plate

e procedure and general operation is as follows. The is heated to the starting temperature with the primary l flowing at a selected constant rate (100–200 ml/min). of the refrigerated secondary liquid is also started. The nometer "zero-adjust" knob is then turned so that a ite temperature difference is "backed off"; this is determined by calibration. The extent of this zero suppression he galvanometer used was increased by removing the ng screw stop, thus enabling the suspension to take up turns. Should the light spot not be to the left of L_3 this operation, it is brought to this position by momen- opening valve S_2 (Fig. 1) and allowing refrigerant into xchanger. The natural tendency now is for the tempera- differential to decrease and the spot to drift to the right. n it reaches L_3 the first very short pulses of refrigerant and cooling commences. Within a minute or two, the assumes some equilibrium position, more or less on the and portion of lens L_3 and cooling proceeds automati-

It is evident that increasing amounts of refrigerant are sary as cooling continues, in order to maintain the same ng rate. This is reflected in the gradual shift of the spot e right across L_3 and a corresponding reduction in the erature differential. The influence of this on the cooling however, is rendered insignificant by correct shaping of chopper plate and suitable choice of galvanometer tivity. The latter depends to some extent on the cooling itions required, but experience has shown that a sensi- at the receiving lens L_3 of 40 mm/° C is generally satis- ry. For the more rapid cooling rates and for extending cooling ranges, the Saunders valve S_2 provides a means -passing the plunger valve and supplying an additional, nuous, flow of refrigerant. On the other hand, for slow ng at high temperatures, the smallest duration pulse can o large, in which case another valve S_1 enables the flow to be limited. When necessary, adjustments are made to these valves as the temperature falls, so that automatic control is retained.

The necessity for eliminating significant natural heat leakage from the block was mentioned earlier. It is clear that such losses would not be automatically corrected, since its effect on the block thermocouple would move the light beam to the right and produce an increased flow of refrigerant contrary to the immediate needs of the system. It was also mentioned that when operating at high block temperatures, rather large heat losses occur from the primary pipe system, despite heavy lagging, which for a short temperature interval can sometimes be greater than the desired cooling rate. To counteract this and, in addition, to assist in preliminary adjustments to equilibrium, heat is supplied to the primary liquid by a small heater situated in the reservoir R and controlled by a Variac transformer. This is used to balance the heat loss at the beginning of an experiment and bring the temperature of the block to a steady value. The cooling control gear then operates against this heat input until the cooling rate due to leakage is smaller than the selected forced rate, whereupon the heater may be switched off. The system automatically adjusts itself to the change in thermal conditions. Prolonging the duration of this heating unduly adds an unnecessary load to the refrigerating equipment. In some circumstances, slow cooling for example, it is sometimes better to reduce the heating in one or two steps before finally switching off. Preliminary calibration provides the necessary data.

The precision of the control depends to some extent on the cooling rate. In typical runs at about 1° C/min down to ambient temperature, the temperature of the inert substance was plotted against time at minute intervals. Fluctuations about the best straight line through the points were found to be generally not more than $\pm 0{\cdot}05°$ C.

OTHER APPLICATIONS

Other applications have been found for the apparatus described, notably the controlled cooling of a small oil or water bath (one gallon Dewar vessel). It is only necessary to connect the cooling coils of the bath in place of those of the block and transfer the thermoelement from the latter to a glass tube supported in the bath. The bath liquid must be vigorously stirred. For linear cooling curves, the rather large natural heat losses from the open bath must be eliminated. This is easily done as before by progressively reducing, either continuously or in steps, the power supply to a calibrated heater in the bath as cooling proceeds. This could very well be done with a power-driven Variac transformer. The operation need not be very precise, since it is only necessary to arrange that the heating at any time is equal to, or greater than, the losses; any excess is, within limits, automatically absorbed by the refrigerating system. The control precision attainable when cooling a bath at about 1° C/min is such that deviations from the linear rate curve are generally within $\pm 0{\cdot}1°$ C. Slightly closer control is obtained at lower cooling rates.

Other applications of this control system in the laboratory seem possible; one under consideration at present, for example, is the regulated cooling of a microscope stage.

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Surge diverters using trigatrons

By T. E. Broadbent, M.Sc., Ph.D., and A. Fernandez, B.Sc., Ph.D.,* Electrical Engineering Department, University of Manchester

[*Paper first received* 23 *April, and in final form* 24 *July*, 1959]

The work described shows that a single-stage trigatron surge diverter is a simple and effective method of removing the voltage from a specimen once the breakdown initiation process occurs. With solid specimens, the device is of value in enabling breakdown tracks to be observed, whilst with gaseous specimens the diverter can conveniently be used in the study of the filamentary discharges which occur during the breakdown initiation process. The results of detailed experiments designed to investigate the performance of trigatron surge diverters at direct voltages up to 1000 kV are discussed.

In a recent investigation into the intrinsic electric breakdown of alkali halides, accurate measurements of the direction of the breakdown track in thin specimens were required.(1) It was therefore essential to preserve the filamentary track produced in the early stages of breakdown and not to allow the destruction of this initial track by the follow-through energy of the discharge. Some form of surge diverter was therefore necessary, the requirement of this being that once breakdown occurred in the crystal, the energy of the voltage source should be bypassed to earth through the surge diverter and not be dissipated in the crystal, thereby causing destruction of the initial breakdown track. The diverter should therefore act as a switch in parallel with the specimen, and should close (thus removing the voltage from the specimen) as soon as the specimen starts to draw current at the initiation of the breakdown process.

For the purpose of the research programme described above, a circuit has been devised using a trigatron(2) working in air as the high-voltage switch. The circuit is shown in Fig. 1. The principle of the system is that, as soon as the initial breakdown process occurs in the specimen, the current flow through R_1 and R_2 causes a voltage drop across R_2. Provided R_2 is not negligible compared with R_1, this voltage will cause breakdown of the trigatron annular gap and, provided the trigatron gap length is set within certain limits, breakdown in this gap will follow with a very short time delay.(3) Therefore, almost all the energy of the discharge is dissipated in the trigatron and the initial breakdown track in the test specimen remains undamaged and is thus available examination.

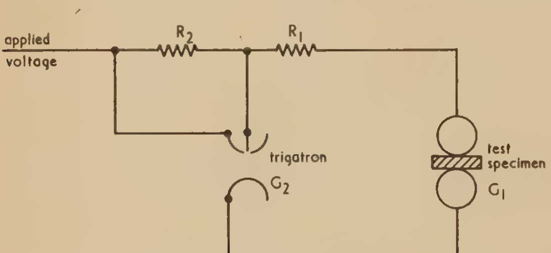

Fig. 1. Circuit for trigatron surge diverter

Previous investigators have used trigatron energy diver but of a more complex nature than that shown in Fig Watson and Higham(4) have described a single-stage de using 12 cm diameter trigatron electrodes and workir voltages up to 125 kV. The trigatron tripping pulse derived using a polarity-correcting circuit, amplifier thyratron. A three-stage trigatron surge diverter using 15 diameter trigatron electrodes and operating at voltages up 300 kV has been described by Sletten and Lewis.(5) attempt to use this device in an investigation of the breakd of transformer oil has subsequently been made by Ham and Tropper,(6) but the diverter was found to be unsuita for their experiments.

A surge diverter of the type shown in Fig. 1 has bee regular use for two years in connexion with the investiga of alkali-halide breakdown already described, and gives v satisfactory results. In view of this successful operation, characteristics of this device and of other single-st trigatron surge diverters have been studied in detail voltages up to 1000 kV. The purpose of the present wor to report on the performance of these diverters and indicate what factors are important in ensuring succes operation.

EXPERIMENTAL METHODS

All the experiments were carried out with the trigatron air at atmospheric pressure. Trigatron electrode diame of 15, 25 and 75 cm were used. The diameter of the in the sparking surface of each type was 0·8 cm and diameter of the trigger rod 0·25 cm. The 15 and 25 diameter trigatron electrodes were hemispherical exc where otherwise stated. Most of the experiments performed with voltages up to 300 kV (measured to wi ±3%) but the 75 cm diameter electrode trigatron investigated at direct potentials up to 1 MV (measurec within ±5%). Time lags were measured to within 0·0 using a cathode-ray oscillograph of a type descri previously.(7) In these measurements, twenty time lags w recorded for each condition and the maximum, minim and arithmetic-mean lag were determined.

Although the surge diverter can be used with any form test apparatus, most of the experiments were carried out u ark gap as the test specimen because it is more convenient reak down a spark gap in air repeatedly than to prepare rge number of solid dielectric specimens. When investi-ng the performance of the surge diverter with direct ages, the test specimen G_1 (in Fig. 1) took the form of a or-adjusted sphere gap (referred to hereafter as the "test "). The trigatron gap spacing was measured and, with test gap opened wide, the direct breakdown voltage V_{dc} ne trigatron recorded. The voltage was then reduced to e known constant value and the test gap closed until kdown occurred. This process was performed twenty s with a time delay of several seconds between successive kdowns to allow the voltage to become steady, and a rd kept of the number of times the trigatron operated, chopping the voltage on G_1. This process was then ated with different applied voltages. With the voltage than a value V_1, the surge diverter never operated. With ages between V_1 and V_2 the diverter sometimes operated, with voltages between V_2 and V_{dc} 100% operation was ıred. A typical graph showing probability of operation ıown in Fig. 2.

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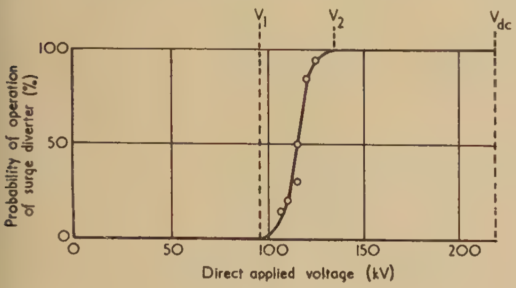
* Dr. Fernandez is now at the University of Mexico.



ig. 2. Typical operating probability curve for surge diverter

Diameter of hemispherical trigatron electrodes = 15 cm
Trigatron gap spacing = 10 cm; positive voltage

the surge diverter is to be of any value, the trigatron t operate satisfactorily each time breakdown is initiated he test gap G_1. The region of voltage $(V_{dc} - V_2)$ in 2 therefore represents a measure of the effectiveness of system, and it is convenient to define a working range of system when used with direct voltages, where the d.c. king voltage is defined as $100(V_{dc} - V_2)/V_{dc}\%$.

'hen impulse voltages are applied to the system, the king range clearly cannot be defined as above. The nique used for impulse investigation was to keep the th of the test gap at a known fixed value (l_1), and to the maximum trigatron gap length (l_2) which still ensures % operation of the diverter. Because in the impulse eriments electrodes of the same diameter were used for trigatron and the test gap, the ratio $(l_2 - l_1)/l_2$ represents easure of the usefulness of the system.

s with direct voltages it is convenient to define the working e arbitrarily, and the impulsive working range is taken as $l_2 - l_1)/l_2\%$.

he requirements of surge diverters for use in applications as that described in the introduction are thus as follows:

) The d.c. working range should be high to ensure the absence of spurious trigatron spark-overs which may occur at voltages approaching V_{dc}.

) The impulse working range should be high to ensure that trigatron breakdown does not occur before the initiation of breakdown in the specimen (or test gap).

(*c*) For both d.c. and impulse working, the time delay between the initiation of breakdown in the test specimen and the operation of the surge diverter should be short. This is to ensure removal of the applied voltage before excessive damage occurs in the specimen.

EXPERIMENTAL RESULTS

D.C. operation of surge diverter. Experiments were carried out with both polarities applied to the system shown in Fig. 1, first using 15 cm diameter and then 25 cm diameter hemispherical trigatron electrodes. R_1 was arranged to be 200 kΩ and R_2 50 kΩ. A typical operating probability curve is shown in Fig. 2. Probability curves such as this were obtained for trigatron gap spacings from 2–12 cm at 2 cm intervals, and a summary of the results is shown in Fig. 3 in the form of working-range curves. The working range is seen to depend on polarity and also on electrode diameter. This is in agreement with previous work using trigatron systems.(3, 8) With positive voltages and 15 cm diameter trigatron electrodes, the working range is greater than 33% over a range of gap spacings of 2–12 cm, corresponding to direct trigatron breakdown voltages (V_{dc}) of 58 kV to 240 kV. With negative voltages, however, and using 15 cm diameter trigatron electrodes, the working range decreases rapidly with increasing trigatron gap spacing and, with a 10 cm gap, the working range is only 8%. When 25 cm diameter electrodes are used with a negative voltage, the working range is still only 8% at a gap spacing of 10 cm. These results show that the circuit shown in Fig. 1 is very satisfactory provided a positive voltage is applied but, with large trigatron spacings, the system is unsatisfactory for negative voltage.

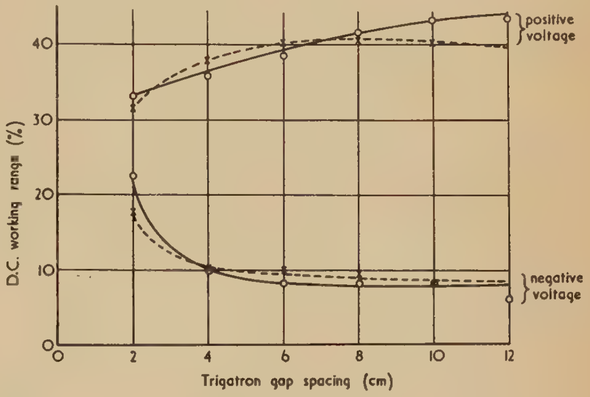


Fig. 3. D.C. working-range curves for system shown in Fig. 1

○ 15 cm diameter trigatron electrodes
× 25 cm diameter trigatron electrodes

Experiments were next carried out to investigate the effect of varying the parameters of the circuit shown in Fig. 1. In each experiment, one parameter was varied, the others remaining unchanged. The following variations were investigated:

(*a*) Reversed connexion to the central trigger rod of the trigatron and the hemisphere surrounding this rod.

(*b*) Resistance values changed such that R_1 is 50 kΩ and R_2 is 200 kΩ (that is, tapping changed but total resistance remaining as before).

(*c*) Resistance values reduced such that R_1 is 20 kΩ and R_2 is 5 kΩ (that is, total resistance reduced but ratio R_1/R_2 as in the original experiment).

(*d*) Circuit modified to that shown in Fig. 4 (that is, resistances on earthed side of the specimen). R_1 is 200 kΩ and R_2 is 50 kΩ.

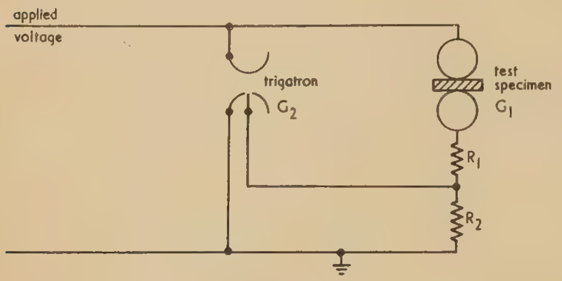


Fig. 4. Circuit of surge diverter with resistances on earthed side of specimen

The results of these experiments are shown in the table, which also gives for comparison results obtained with the basic circuit of Fig. 1 and the original values of resistances. The effect of reversing the connexions to the hemisphere—Experiment (*a*)—is to produce a general increase in working range, the value of the increase depending on polarity, trigatron electrode diameter, and electrode spacing. This result is in agreement with previous work on the trigatron(3) in which it has been shown that, for best results, the sign of the trigger voltage with respect to the main electrode enclosing the trigger rod should be opposite to that of the other main electrode.

Experiment (*b*) shows that little change in working range is produced by altering the relative values of R_1 and R_2, the sum of these resistances remaining unchanged. The effect of decreasing the value of total resistance ($R_1 + R_2$) whilst retaining the same ratio R_1/R_2—Experiment (*c*)—is to cause a slight reduction in working range.

The purpose of Experiment (*d*) was to observe if the results with positive voltages applied to the circuit of Fig. 4 would be the same as those for negative voltages applied to the circuit of Fig. 1 and *vice versa*. The table shows that this is not so, possibly because of the quite different stray capacitances to earth of the circuits shown in Figs. 1 and 4. However, the results indicate that, as might be expected, a rea ably high working range (greater than 23% for all condit tried) is obtained when a negative voltage is applied to system shown in Fig. 4 while, when a positive voltag applied, the working range is low. Thus, the circuit of F is suitable for negative voltage and that of Fig. 1 for posi

The time lag between the initiation of the discharge in specimen (or test gap) and the breakdown of the triga should be small, and measurements were therefore mad find the value of this lag using the circuit of Fig. 1. value of R_1 was 20 kΩ and of R_2 5 kΩ. Typical results shown in Fig. 5, taken for an applied voltage of 160 With a positive voltage, the mean time lag was less 0·5 μs over a range of trigatron gap spacings from 6–1 while, with a negative voltage, the time lag was again s but over only a small range of gap settings. Further exp ments with a positive voltage of 200 kV showed the m time lag to be less than 0·5 μs over a range of trigatron settings from 6–16 cm.

In the experiments already described using a 2 diameter hemispherical trigatron electrode, the meas voltage V_{dc} increased only slightly with increasing vol at gap spacings greater than 12 cm. This was caused by highly unsymmetrical nature of the gap at large spacings,

Effect of varying the parameters of the circuit shown in Fig. 1

Trigatron electrode diameter (cm)	*Polarity*	*Trigatron gap spacing (cm)*	*D.C. working range (%)*				
			Standard conditions (Fig. 1) $R_1 = 200$ *k*Ω $R_2 = 50$ *k*Ω	*Modified circuits*			
				(*a*) *Connexions to hemisphere reversed*	(*b*) *Tapping on resistors changed* $R_1 = 50$ *k*Ω $R_2 = 200$ *k*Ω	(*c*) *Reduced value of dropping resistance* $R_1 = 20$ *k*Ω $R_2 = 5$ *k*Ω	(*d*) *Resistance earthed side specimen (Fig.* $R_1 = 200$ *k* $R_2 = 50$ *k*
15	positive	2	33	37	29	26	24
	positive	10	43	50	43	44	1
	negative	2	23	24	19	11	28
	negative	10	8	11	6	7	23
25	positive	2	31	41	32	26	21
	positive	10	40	53	36	34	0
	negative	2	18	21	18	10	28
	negative	10	8	14	5	4	25

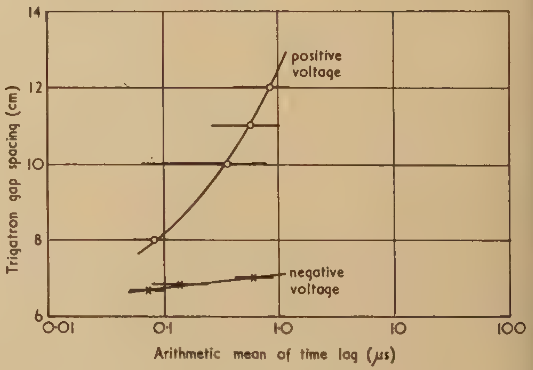


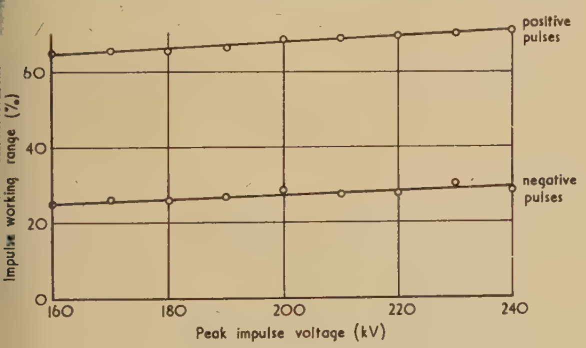
Fig. 5. Time-lag curves or circuit of Fig. 1 using dire applied voltage

Voltage = 160 kV; diameter of hemispherical trigatrc electrodes = 15 cm

(Horizontal lines represent spread from minimum to maximu time lag in 20 records.)

kdown, in fact, frequently occurred to the edge of the ispheres. It was thought that, by using a trigatron in ch both main electrodes were spherical (the trigger rod g enclosed by a sphere instead of a hemisphere), a er working range would be produced, because of the e uniform field between the spherical electrodes. Experi- ts were therefore performed with positive voltages using cm diameter trigatron of this type. These show that a king range greater than 33% is produced over a range ine gap lengths from 4–30 cm (corresponding to measured es of V_{dc} from 110–438 kV). A marked improvement is produced by the use of spherical trigatron electrodes.

npulse operation of surge diverter. Inspection of the uit shown in Fig. 1 indicates that, when an impulse age is applied to the system, a voltage is produced across ecause of the displacement current in G_1. If the rate of of the applied impulse is greater than a certain critical e, the voltage across R_2 might be sufficient to cause k-over in the trigatron annular gap, thus firing the tron main gap. The trigatron might then fire before initiation of breakdown in G_1. Experiments were there- carried out to find the maximum rate of rise of voltage ch could be applied to the system shown in Fig. 1 without g of the trigatron occurring because of the displacement ent through G_1. The resistance R_1 was set at 20 kΩ R_2 at 5 kΩ. It was found that, using flat-topped pulses 60 kV peak value, the critical wavefront time (to 90% value) was about 10 μs. The impulse working range investigated with flat-topped applied impulses having a efront time of 16 μs, and the results are shown in Fig. 6. n the d.c. experiments described previously, the working ge is higher with a positive than with a negative voltage.



ig. 6. Impulse working-range curves for circuit of Fig. 1

st-gap (G_1) spacing = 6 cm; diameter of hemispherical trigatron electrodes = 15 cm; wavefront time ≃ 16 μs

easurements were made to find the time delay between nitiation of breakdown in the test gap and the breakdown he trigatron. Positive pulses of 200 kV peak and 16 μs efront were applied to the circuit shown in Fig. 1, with qual to 20 kΩ, R_2 equal to 5 kΩ and G_1 equal to 6 cm. mean time lag was less than 0·5 μs over a range of tron gap spacings from 6–13 cm. With positive pulses 60 kV peak, the mean time lag was less than 0·5 μs over ange of trigatron spacings from 6–11·5 cm. When tive pulses of 200 kV were applied, the same mean time occurred over a range of trigatron settings of 6–8·4 cm, e, with 160 kV pulses, the range was 6–7·4 cm. The imum time lag was not more than twice the mean value ny of the cases quoted above. Thus short time lags occur a high range of trigatron gap spacings with positive voltages, but over a relatively low range with negative voltages.

Experiments were performed with a wavefront time less than that required to produce a displacement current spark in the trigatron annular gap. These indicated that the system shown in Fig. 1 was workable but over a much smaller working range than in the experiments already described for slower wavefronts. The reason the system operates at all with fast wavefronts might be that the low energy of the displacement-current spark in the trigatron annular gap is not sufficient to ensure rapid breakdown in the trigatron main gap. The high-energy discharge in the trigatron annular gap produced by the initiation of breakdown in G_1 might therefore fire the trigatron main gap before this gap breaks down because of the effect of the low-energy displacement-current spark. If this explanation is correct, it might be expected that the working range actually obtained depends to a high degree on the stray capacitance to earth from various parts of the circuit. Experiments showed that this was, in fact, so. For instance, with positive pulses of 0·8 μs wavefront applied to the circuit of Fig. 1 using a resistance ($R_1 + R_2$) 4 ft in length (with R_1 equal to 20 kΩ and R_2 equal to 5 kΩ), the working range increased from 18% with 160 kV pulses to 74% with 240 kV pulses. With a resistance of the same value but 8 ft in length, the working range under similar conditions was lower, increasing from 12–64%.

Measurements showed that with wavefronts fast enough to produce a trigatron displacement-current spark, the useful operating range of the system was a few per cent less than in the figures quoted above. This is because, with a trigatron gap spacing less than a certain value (that is, when l_2 is only a few per cent in excess of l_1), breakdown might occur in the trigatron before the breakdown process begins in G_1.

Double trigatron surge diverter. The experiments described above show that the circuit of Fig. 1 ensures a high working range, provided the applied voltage is positive, while that of Fig. 4 ensures a high working range with negative polarity. It might be expected, therefore, that a triggering mechanism in each of the main electrodes of the trigatron would give a high working range for applied voltages of either polarity. A circuit was therefore set up as shown in Fig. 7, using 15 cm diameter hemispherical trigatron electrodes. The system was investigated using direct voltages over a range of trigatron gap spacings from 2–12 cm at 2 cm intervals. The resistances R_1 and R_2 were each 20 kΩ. With positive polarity, the working range increased from 36% for a 2 cm trigatron gap spacing to 42% with a spacing of 12 cm. With a negative charging voltage, the working range decreased from 36% with a 2 cm gap to 26% for a 12 cm gap. Time lags between the initiation of breakdown in G_1 and the breakdown of G_2 were then measured, with a G_2 equal to 8 cm. The maximum time lag with either polarity was found to

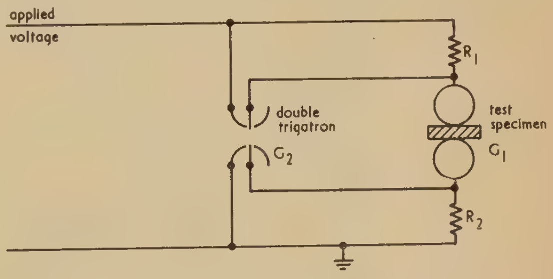


Fig. 7. Circuit for double-trigatron surge diverter

be less than $0{\cdot}1\ \mu s$ over a range of applied voltage from 130–180 kV. These results show that with a given trigatron electrode spacing, the double trigatron works very satisfactorily with both polarities over a wide range of applied voltage. With a fixed applied voltage, good operation would therefore occur over a wide range of trigatron gap spacings.

Photographs of the spark channel. The circuit was set up as in Fig. 1 with an 8 cm gap spacing between 15 cm diameter spheres as the test gap G_1. The value of R_1 was set at 20 kΩ and R_2 at 5 kΩ. Impulse voltages were then applied and the spark channel in G_1 photographed, first with the trigatron gap G_2 arranged widely enough not to operate, and then with this gap operating. Many photographs were taken and typical records are shown in Fig. 8. Without the diverter, a bright diffuse channel was obtained in G_1, while the photographs of Fig. 8 show that, with the surge diverter in circuit, the fine filamentary nature of the breakdown initiation channel can be clearly observed. It will be further observed that for a positive and a negative applied voltage the character of the branching is quite different, and it is hoped to investigate this shortly with the aid of the surge diverter. The photographs shown in Fig. 8 clearly indicate the usefulness of the trigatron surge diverter in the fundamental study of spark channels in gases.

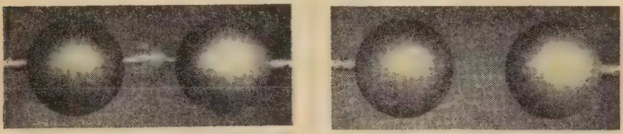

(*a*) (*b*)

Fig. 8. Photographs of spark channel in G_1 (surge diverter operating)

(*a*) positive voltage; (*b*) negative voltage
Diameter of electrodes of G_1 = 15 cm; G_1 gap spacing = 8 cm
Left-hand electrode in (*a*) and (*b*) earthed

During the investigation into the directional electrical breakdown of alkali-halide crystals already mentioned,$^{(1)}$ many photographs of the spark channel were obtained using a surge diverter of the type shown in Fig. 1 and a crystal specimen as G_1. A typical photograph in which the narrow breakdown initiation channels in potassium chloride can be clearly observed, has been published previously$^{(1)}$ and is therefore not reproduced here. To obtain such spark-path photographs, the use of the surge diverter was essential. Without it, the initial track was destroyed by the energy of the discharge.

1 MV. operation. Experiments were carried out to investigate the performance of the surge diverter at direct voltages up to 1 MV, using 75 cm diameter spheres for the trigatron main electrodes and a motor-adjusted gap with 100 cm diameter spheres as the test gap G_1. The physical structure of the equipment was such that the circuit shown in Fig. 4 was the most convenient to set up, and this was therefore used. The resistances R_1 and R_2 were each $6{\cdot}6$ kΩ. D.C. working-range curves were obtained, and these are shown in Fig. 9. These show that, as found in the work described above on the circuit of Fig. 4, the working range when the applied voltage is negative is considerably greater than when the polarity is positive. It is also seen that, with negative polarity, a reasonably high working range is obtained with direct charging voltages up to 1 MV. With the circuit arranged as in Fig. 1, a high working range with positive polarity would be expected.

The time delay between the initiation of breakdown in and the breakdown of G_2 was measured for trigatron spaci of 10–60 cm at 10 cm intervals. For both polarities and each trigatron spacing, the maximum time lag was less th $0{\cdot}5\ \mu s$ over most of the voltage range for which the trigat would operate.

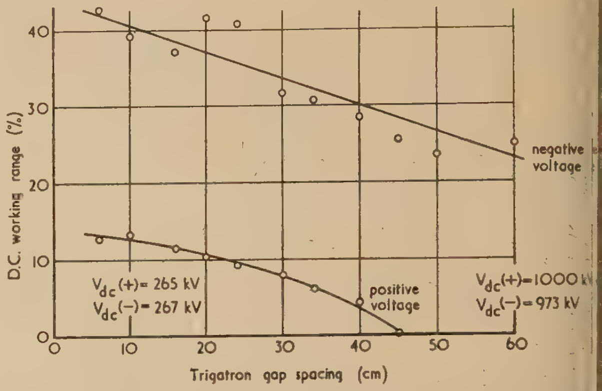


Fig. 9. D.C. working-range curves for circuit of Fig.
Diameter of spherical trigatron electrodes = 75 cm

CONCLUSIONS

The work described above shows that a single-st trigatron surge diverter is a simple and effective metho removing the voltage from a test specimen once breakd initiation occurs. With solid specimens, the device is value in enabling breakdown tracks to be observed wh with gaseous specimens, the diverter can conveniently used in the study of the filamentary discharges which oc during the breakdown initiation process.

Surge diverters of the type described may be used w direct or impulse voltages applied to the specimen. T operation of the surge diverter when an alternating volt is applied has not been investigated but there appears to no reason why satisfactory operation should not occur.

Tests with large-diameter electrodes showed that the syst operated satisfactorily using one stage only at direct volta up to 1 MV. The device should therefore be extremely use in future investigations on the directional breakdown eff in solid specimens of large thickness, or in the study of sp channels in long gaps in gases.

The performance of trigatron surge diverters depends some extent on the particular set-up in use, because of effect of such factors as stray capacitance and the size a shape of the trigatron electrodes. It is believed, howev that the results quoted are of value in indicating wh factors are or are not important in the operation of su surge diverters.

ACKNOWLEDGEMENTS

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Apparatus for combined thermal analysis and dilatometry

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An apparatus is described for carrying out simultaneous differential thermal analysis and dilatometry on small metallic samples at temperatures up to 1 200° C in a vacuum. Automatic temperature control and recording are important features of the method, and a discussion of the chief sources of error is given.

r several years, work has been proceeding at the Atomic ergy Research Establishment, Harwell, on the determination the equilibrium diagrams for various plutonium alloy tems. A considerable part of the information has been vided by differential thermal analysis and dilatometric dies of the alloys; the thermal analysis method involves omatic control and recording and has been briefly desbed elsewhere.(1) The dilatometry was originally carried out a simple silica vacuum dilatometer(1) and since it involved ual recording of data, it proved time consuming. Various rkers at this establishment(2, 3) carried out the two methods nultaneously in a single piece of apparatus, but without oiding the problem of the visual recording of the dilato- tric data; the present authors' aim was to construct such an paratus to be automatic both in controlling and in recording. Since the dilatometric technique was only required for the ection of phase changes and not for the determination of expansion coefficients, it was possible to use a method of slightly lower accuracy than that originally employed. The features that were required in the apparatus were ease of handling, compactness, a maximum temperature in the region of 1 200° C and ability to be cycled between pre-set temperatures; the first two were necessary since the apparatus had to be fitted into a glove-box for handling the highly toxic α-active plutonium samples, whilst the final feature was to enable the apparatus to run overnight without attention.

APPARATUS

The apparatus was built in duplicate, both furnace units being contained in the same glove-box (Fig. 1). A single rotary pump backed two diffusion pumps, one serving each furnace, to give a vacuum of better than 5×10^{-5} mm of mercury at temperatures up to 1 200° C. The whole of the vacuum system was contained in the glove-box.

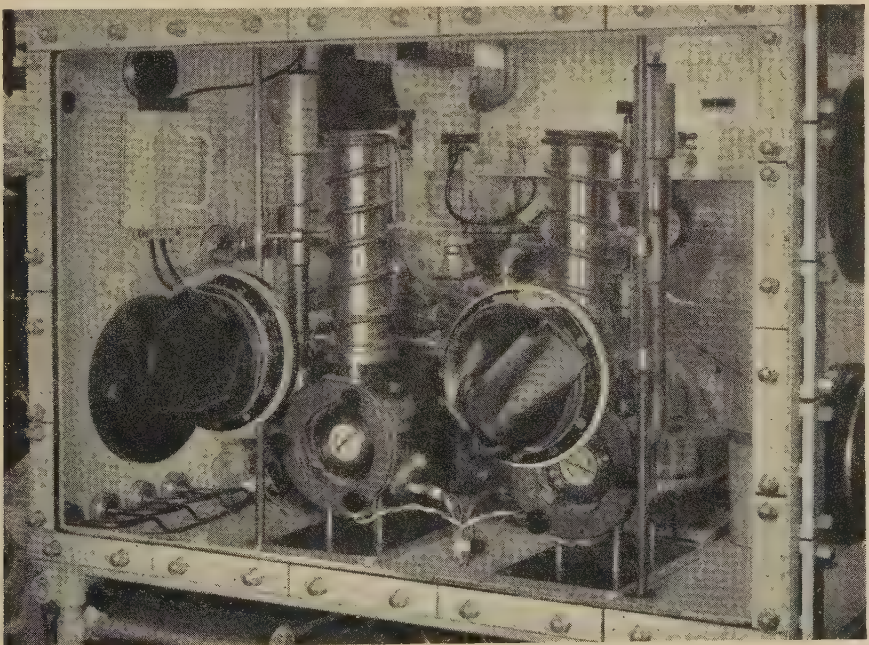

Fig. 1. Combined thermal analysis and dilatometry apparatus in a glove-box

(*a*) *The vacuum furnace.* This is shown in Fig. 2. The vacuum container is a water-cooled brass cylinder, 3 in. in diameter and 12 in. long, the lower end resting on an O-ring seal. The container can be raised vertically on a sliding arm to allow access to the furnace.

The furnace itself is constructed from two parallel silica tubes of unequal length, the longer being the dilatometer tube whilst the shorter provides similar furnace conditions for the thermal analysis reference block; the specimen and reference block are mounted side by side. Alumina rods, 1·5 mm in diameter, cemented along the main tubes separate the furnace windings from the silica; 4 mm diameter alumina rods similarly support the radiation shields which can slide down to allow visibility when loading. The rods and tubes are cemented at each end into pyrophyllite formers.

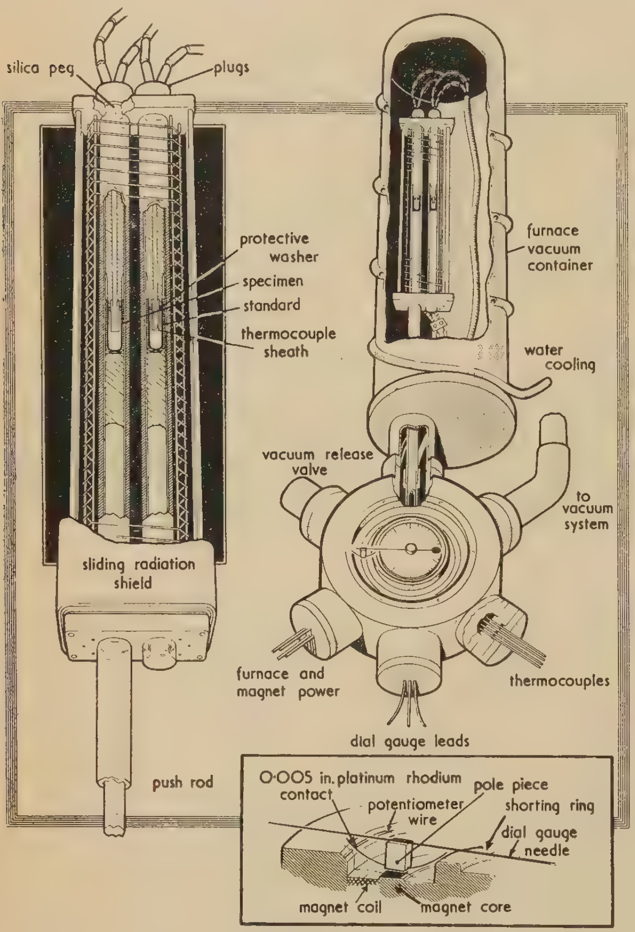

Fig. 2. Diagram of apparatus for thermal analysis and dilatometry

Inset. Detail of dial gauge needle contact

Interchangeable furnaces are used, non-inductively wound with either 30 s.w.g. Nichrome or 32 s.w.g. molybdenum wire at a rate of 12 turns/in. For reasons given in the discussion, the Nichrome furnace is preferred, the molybdenum one only being used for high-temperature work. A third alternative has been to use a platinum furnace, but this has proved more fragile than the others. Comparatively low ratings are a feature of all the furnaces, 200 W being sufficient to raise the specimen to 1 200° C.

(*b*) *The dilatometer.* The dilatometer consists of a 2¼ in. diameter dial gauge mounted upside down in a modified phosphorus pentoxide vacuum trap, the top of which carri the flange to which the furnace vacuum container is seale A piece of heavy walled silica capillary is used to plug the t end of the dilatometer tube and is held in position by removable silica peg. The plug projects to the centre of t furnace, the lower end being ground down to allow free mov ment of the crucible which contains the specimen To preve reaction between the specimen and the plug, a thin disk tantalum or alumina is inserted between them. The specim and crucible rest on top of the silica push rod; the lower e of the push rod has a ball bearing cemented to it, whilst t plunger of the dial gauge is ground flat. Various sizes push rods and plugs are available to cater for different siz of specimens.

The specimen temperature is measured by a thermocoup which passes down the silica plug, the head of the coup being sheathed in tantalum (0·007 in. wall thickness) alumina (0·015 in. wall thickness). This sheath is inserted a hole drilled into the centre of the specimen. The therm couple is of either chromel/alumel or platinum/platinum–13 rhodium, 0·010 in. diameter wire being used in either cas the wires are individually protected by thin-walled alumi tubes.

The actual dial gauge was modified to make it reco automatically, the principle employed being similar to th used by Haynes.$^{(4)}$ A single turn potentiometer wire 0·010 in. diameter platinum–13% rhodium is mount concentrically around the edge of the dial gauge. Inside t is an electromagnet and shorting ring (inset, Fig. 2); the nee of the dial gauge has been modified so that it carries a s iron pole piece and a length of 0·005 in. diameter platinu rhodium wire, the latter making contact between the pote tiometer wire and shorting ring whenever the magne energized; this is controlled by a switch in the recorder that it synchronizes with the plotting period of one of the fo points in the recorder. The resultant trace thus reads potential difference directly proportional to the deflexion the dial gauge. When the recorder is plotting on any of t other three points, the needle is free to rotate. A very sm gap is necessary between the ends of the potentiometer wi but this only corresponds to 0·000 05 in. dilatation.

The sensitivity of the gauge can be varied by altering t current flowing through the potentiometer wire; genera 1 mV per 0·001 in. is used, a great advantage of this particu setting being that the recorder trace automatically sets its up every 10 mV, the full-scale range of the recorder bei 12 mV. Because of the resistance of the rest of the circu the zero point of the dial gauge corresponds to a reading about 0·5 mV on the recorder.

A simple potentiometric circuit is used to provide t potential drop along the platinum–rhodium wire, the source the potential being Le Carbone cells which give a hig stable e.m.f. at the low loadings used.

(*c*) *Thermal analysis.* The differential thermal analy trace is obtained by amplifying the difference between t previously mentioned specimen thermocouple and a simi couple, immersed to the same depth in a reference block the second silica tube. This reference block, which is usua of tantalum, is of similar dimensions to the specimen. Owi to the similarity of the specific heat values, this leads to matc ing thermal capacities, thus reducing the background dr of the difference trace. The specimen thermocouple th serves the dual purpose of recording the specimen temperatu and acting as one half of the differential couple. T differential e.m.f. is amplified by a d.c. amplifier, the inp circuit of which contains a sensitive galvanometer; since t rder is temporarily out of balance when switching from point to another it can feed back a relatively large e.m.f. the galvanometer through the common thermocouple uit. A switch, actuated by the recorder, has therefore been ed in the circuit to prevent damage to the galvanometer. ne amplification factor is usually about ×50 for platinum/ num–rhodium couples and ×20 for chromel/alumel oles. Under these conditions, the long term drift of the rence trace is less than 5 mV so that the recorder requires etting up; the short term stability is usually better than μV on the trace for the quoted amplification factors. hen chromel/alumel couples are used, they are checked ntervals against the melting point of various reference als. A small correction usually has to be made to the arent temperature, but this has proved to be constant to C for any one batch of chromel/alumel wire as matched he manufacturers.

ne cold junction is maintained at a temperature constant 0·1° C by electrical means.

) *Furnace control.* Both the thermal analysis and the ometry require an approximately linear heating rate. is provided by altering the output setting of a variable sformer by means of a motor driven cam. The shape of cam is arrived at by finding the voltages required to heat furnace to temperatures of 100, 200, 300° C and so on up maximum of 1 200° C. The cam is then cut so that the ances along the perimeter between any two of these ngs are equal; the cams used are of aluminium and teeth cut in them with a gear cutter. The drive is provided by ared-down 1 rev/min motor fixed to a trolley on guides tensioned by springs against the perimeter of the cam. rate of heating can be varied either by altering the voltage lied to the variable transformer or by changing the dia- er of the gear wheel driving the cam.

o control the range of the heating and cooling cycle, istable stops are placed on the cam; these actuate two ro-switches carried by the driving motor trolley which in reverse the motor through a system of relays. The at the low temperature end can be set for either a single multiple cycle; in the former case the motor and furnace switched off, and also the recorder if so desired. To ment this system, adjustable relays have been placed on recorder scale and are actuated by the pen carriage. se are only energized when the temperature is plotting provide a more accurate method of reversing the motor at e-chosen maximum temperature. In the event of the mocouple breaking, the cam stops provide a safeguard. y are also used when the thermal cycle is required to go tly outside the recorder range, e.g., to overcome hysteresis ciated with a change that occurs close to the bottom end e recorder range on heating, and in this case the recorder s are shorted out.

DISCUSSION

ne accuracy of the dilatometric work is limited by a ber of factors. The chief of these are given below.

) The mechanical accuracy of the dial gauge; this is a very minor error compared with some of the subsequent ones, being less than 0·000 05 in. for the maximum dimensional changes observed.

) Temperature gradient between the main tube and the push rod; for heating rates of the order of 2° C/min, this is not significant when the apparatus is built of silica. However, an alumina furnace and push rod system built for use at high temperatures is adversely affected by this, the outer tube expanding more rapidly than the push rod. Minor changes of slope in the trace tend to be obscured by this but major changes are still easily detected.

(3) The setting of the potentiometer wire around the dial gauge; more than any other factor this limits the maximum sensitivity which may be used without the background wander of the trace becoming excessively high. In practice, the maximum useful sensitivity has been found to be 0·001 in. extension equivalent to 5mV on the recorder, i.e. a total magnification of about ×5 000.

(4) Variation with temperature of the resistance of the potentiometer wire; this can cause a long term drift of the trace, but in fact has proved to be slight, little heat being transferred from the furnace to the dial gauge. For work at temperatures above 1 200° C with the alumina furnace and push rods, a water-cooled jacket is to be fitted to the bottom flange of the furnace container. Even without this water cooling, it has been observed that the maximum change in sensitivity due to this is far less than 1% over the operating range of temperatures.

(5) Thermal gradients in the specimen; these have been minimized by using specimens not more than ½ in. in length and by carefully positioning the specimen in the centre of the furnace where the gradients are lowest. Observations at known horizontal arrests suggest that the maximum temperature difference over the specimen is very much less than 5° C.

(6) Creep of the specimen; many of the specimens used have proved to be very soft at temperatures within 100–200° C of their melting point. To reduce the creep of the specimen, the weight of the push rod should counterbalance the spring in the dial gauge at the start of the run. This can be done by either using hollow push rods of different weights or supplementary springs in the dial gauge; the latter method has been used in the present case.

The performance of the differential thermal analysis is mainly controlled by the maximum possible amplification without instability of the trace occurring. Excellent traces can be easily obtained up to 900° C, but above this temperature, the quality deteriorates unless certain precautions are taken. Thus if the apparatus has molybdenum windings or radiation shields, the couples must be continuously shielded from the hot zone to a point well clear of the furnace or, in spite of the vacuum of 5×10^{-5} mm of mercury, deposition of traces of the volatile molybdenum oxide occurs on the cooler sections of the alumina insulators, giving a fluctuating leak to earth from the couples; this is sufficient to produce instability in the amplified trace. To overcome this effect either the molybdenum furnace and radiation shields are replaced by a platinum furnace with nickel radiation shields or all the gaps in the thermocouple insulators are cemented up with pure alumina cement. A similar deterioration of the trace occurs if tantalum crucibles and sheaths are used in the silica apparatus, the leakage to earth again proving serious; this is easily cured by insulating the head of the couple from the tantalum sheath with a little alumina cement.

Screening of the thermocouple leads inside the vacuum did not effect any further improvement in the trace; this was as expected since the furnaces are non-inductively wound. The thermocouple leads outside the vacuum have been shielded as a normal precaution when measuring small potential differences in a laboratory containing many other pieces of electrical apparatus.

Owing to the presence of the pumping system inside the glove-box, the whole apparatus vibrates slightly; this is beneficial in preventing sticking of the dilatometer but care must be taken to see that the couple head does not vibrate relative to its sheath, or the thermal analysis trace is affected.

This apparatus has proved very satisfactory on many plutonium alloys and has also worked well on some surprisingly small samples; these were of neptunium and its alloys, an extremely scarce metal, and were in the form of flat beads about $\frac{1}{4}$ in. diameter and $\frac{1}{8}$ in. thick, the weight being often less than 1 g.

ACKNOWLEDGEMENT

The authors would like to thank J. A. Lee for much help advice on the design of the apparatus.

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Improved apparatus for floating-zone melting by electron bombardment

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An improved apparatus for floating-zone melting by electron bombardment is described. Provision is made for zoning speeds of 0–350 cm/h with bombarding voltages up to 10 kV at 500 mA. The operating vacua are of the order 10^{-6} mb or better. Up to 22 cm of specimen length can be zoned.

The melting of a floating zone in a vertically suspended specimen rod by electron bombardment was first described by Davis, Calverley and Lever(1) and later more fully by Calverley, Davis and Lever.(2) This process has two main advantages. First, molten zones may be attained in the more refractory materials with a very small power input. Second, a narrow molten zone, which is often desirable(3) for zoning, can be obtained by focusing the electron beam.

A continuous demand for zoned specimens of higher purity and the consequent prospect of having to use semi-skilled operators, has made it necessary to develop an improved apparatus.

DESIGN REQUIREMENTS

Experience with an earlier apparatus(2) showed that the main requirements in the new apparatus were:

(i) A work chamber with adequate cooling and easy access to the interior.

(ii) Good visibility of the specimen during refining.

(iii) Permanent alinement of the upper and lower specimen chucks and cathode traverse mechanism.

(iv) A high-speed pumping system to ensure a vacuum in the 10^{-6} mb range or better, even when considerable outgassing of the specimen takes place.

(v) Automatic control of a zone-refining cycle with zone speeds ranging from 0–350 cm/h, and bombarding power ranging from 5 kW to a few milliwatts.

DESCRIPTION OF THE APPARATUS

The work chamber. It was found that the various design requirements could be most easily incorporated in a rectangular box form chamber constructed of 3–5% magnesium aluminium alloy. This was obtained as a precision-rolled plate to B.S.S. 1477/N.P.5/6 (type M.G.5 by J. Booth and Co. Ltd.) and was selected for the following reasons:

(i) Easy fabrication by argon arc welding.
(ii) Good thermal conductivity.
(iii) Light weight.

The chamber is water-cooled to maintain good vacu conditions and follows very closely the design of the vac chamber for the silicon crystal-pulling furnace described Marshall and Wickham.(4) Cooling grooves are cut into box faces, each face being covered with a plate which in porates the water manifolds. The presence of these groo makes it desirable to have thick sides to the box and theref puts a premium on the use of a light weight material. vacuum seals into the chamber are Gaco "O" rings most which are in contact with the cooling water, and all mov shafts enter through Wilson-type seals.

As the vapour pump is cooled by a separate system, water can be circulated in the chamber cooling chann during the initial stages of pumping down. This outgasses chamber walls and decreases appreciably the time necess to reach the working pressure of 10^{-6} mb.

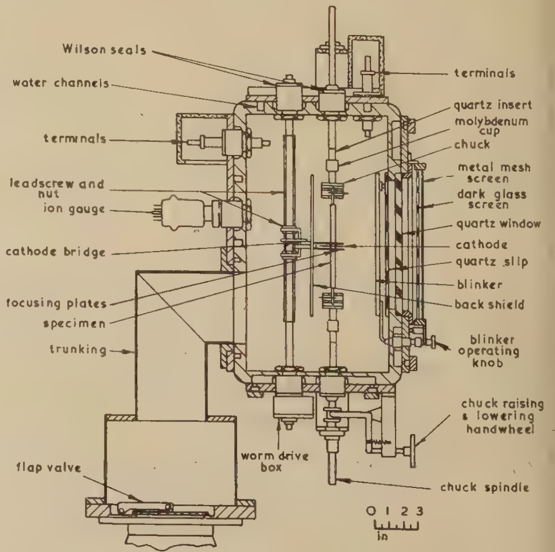


Fig. 1. Sectional side elevation

cess to the interior is by a large water-cooled door on ide of the box. This leaves both the top and the bottom e chamber free for the permanent alinement of top and om specimen chucks and cathode traverse screw.

large quartz glass window (Fig. 1) allows excellent n of the molten zone throughout the traverse. It is cted on the inside by an easily removable, thin, quartz- slip, which in turn can be shielded by a molybdenum er. This blinker prevents evaporated metal obscuring uartz slip, and during working is only opened for the necessary to view the molten zone. A dark glass screen .S.S. 679–6 G.W.–4F is provided externally to reduce , and the operator is protected from implosion by a l mesh screen. Both these screens are easily removable.

ne vacuum system. Because of the possible risk of lgamation between mercury and the aluminium work ber, an oil-vapour diffusion pump is used. A liquid- gen cold trap is incorporated as a precaution against amination of the specimen by cracked oil, which would be difficult to remove from the work chamber walls.

ne work chamber is pumped via 5 in. diameter stainless- trunking and can be isolated by a flap valve. This les the work chamber to be let down to air pressure for ing, adjustments, etc., while still keeping the vacuum m running. The pumping speed is estimated to be l./s. An ionization gauge in the back wall of the work nber allows pressures to be measured as near to the work ossible.

ne cathode traverse system. As will be seen from Fig. 2, specimen is fixed and the cathode moved to traverse the ing zone. This system has the advantage over one of ing the specimen in that it gives a shorter chamber for a n specimen length. Further, if the specimen is moved, extremely difficult to provide a smooth enough movement revent vibration of the molten zone.

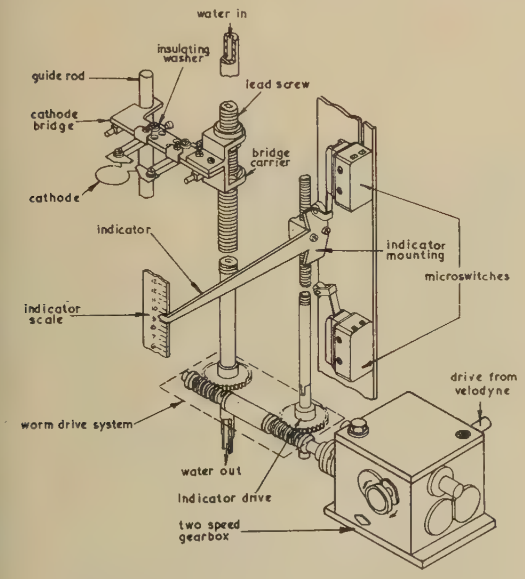


Fig. 2. Cathode traverse system

ne cathode is mounted on an insulated and easily ountable bridge (Fig. 2) which is moved up and down by tating leadscrew. This method has the advantage that se, etc., is not carried into the work chamber by axially- ing rods. The problem of rubbing surfaces in high um has been solved by using a water-cooled leadscrew of G.5 steel (by Jessop), working in an aluminium-bronze nut. All rubbing surfaces are coated with molybdenum disulphide. The traversing system and the cathode bridge are protected from thermal radiation and evaporated metal by a molybdenum shield fastened to the cathode bridge.

The leadscrew is driven by a variable-speed servo-controlled motor through a reduction gear system as shown in Fig. 2. An external indicator makes it unnecessary to open the blinker merely to ascertain the cathode position. The indicator mounting block actuates micro-switches which form adjustable end stops and can be used to control a zone-refining cycle which is described below.

The system provides a smooth and accurate cathode travel over 22 cm, with a continuously variable speed range from 0–350 cm/h.

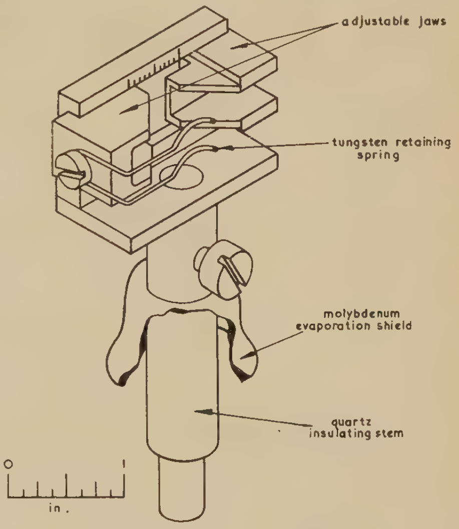


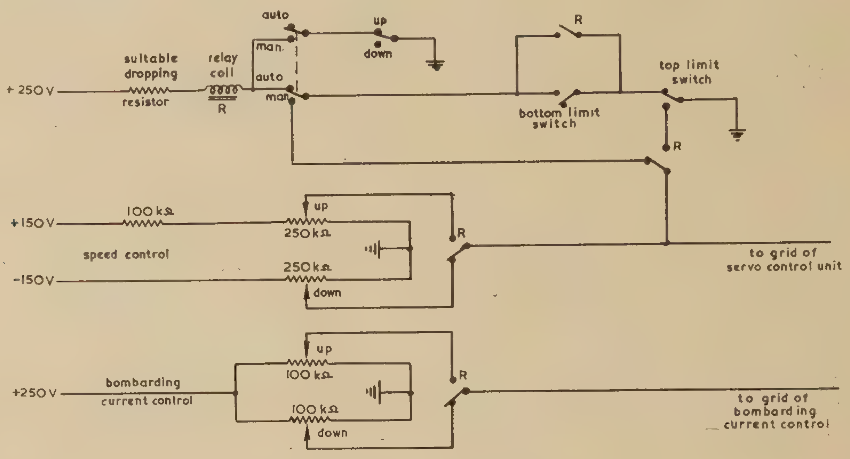
Fig. 3. Chuck assembly

Chuck assemblies. The chuck assemblies are made of molybdenum and are adjustable for rod diameters ranging from $\frac{1}{16}$ to $\frac{1}{2}$ in. (Fig. 3). The specimen is held by tungsten spring clips which allow it to expand and contract during the heating cycle. Quartz insulators in the spindles allow the chucks to be run at a high potential, and cupped molybdenum shields protect the insulators from deposits of evaporated metal which might cause electrical leakage. To accommodate different specimen lengths and to facilitate the normal practice of loading a specimen in two pieces, both chucks have a coarse axial adjustment and are locked in position by clamping screws on the chuck spindles. Rapid adjustment of the axial distance between the chucks is sometimes necessary when zoning, to allow for quick closing-up or joining when necking or breakage occurs and, to some extent, to control zone shape and length. To allow for this, there is a fine adjustment, working on the bottom chuck only, actuated by a handwheel situated underneath the front of the chamber. As it may be necessary at some future time, to rotate the specimen, provision is also made in the chuck spindle mountings for the easy addition of gearbox drives.

ELECTRICAL DESIGN

Electron bombardment system. The apparatus is so designed that the electron bombardment can be done with either the cathode or the specimen at earth potential. The cathode is normally earthed in order to keep the flexible leads to it at a low potential. However, should it prove necessary to rotate the specimen, the cathode would have to be run at a high potential and the specimen earthed because of the impracticability of applying a high voltage to a rotating chuck. With this in mind, all electrodes have been insulated for high-voltage working. The h.t. unit is capable of supplying up to 500 mA at 10 kV, giving a maximum bombardment power of 5 kW.

The cathode is a ring of 0·020 in. diameter tungsten wire and requires approximately 40 A at 6 V to heat it. Although a tape cathode has the advantage of greater rigidity, a wire is used as it enables the molten zone to be seen more clearly. The focusing electrodes are operated at cathode potential, and no attempt has yet been made to design an electrode system which hides the cathode from the molten zone, although this would be very desirable on two counts. Firstly, it would prevent the cathode becoming coated by particles of the specimen thrown out during outgassing on the first melting. Secondly, it would protect the specimen from the possibility of tungsten contamination. However, at the full bombarding voltage, smaller diameter specimens can be zoned with currents of a few milliamps. This allows the cathode temperature to be reduced, and so makes the risk of contamination very small.


auto
up
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bottom limit
switch
R
+150 V
100 kΩ
up
250 kΩ
R
speed control
250 kΩ
-150 V
down
to grid of
servo control unit
up
100 kΩ
R
+250 V
bombarding
current control
100 kΩ
down
to grid of
bombarding
current control

Equipment switched for automatic operation
Zone travelling down. Limit switches open, relay open.

Fig. 4. Line diagram of switching system

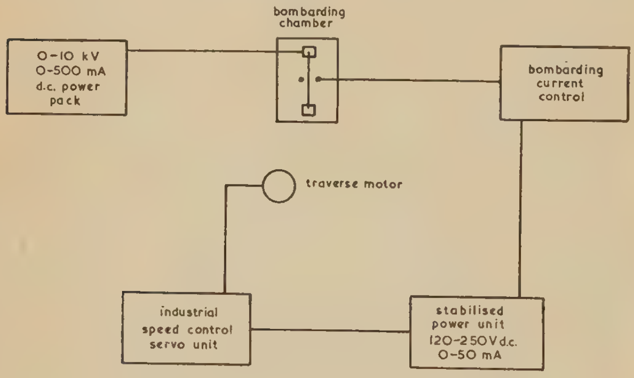
bombarding
chamber
0–10 kV
0–500 mA
d.c. power
pack
bombarding
current
control
traverse motor
industrial
speed control
servo unit
stabilised
power unit
120–250 V d.c.
0–50 mA

Fig. 5. Block diagram of control circuit

Efficient zoning requires that the bombarding power is kept constant. To ensure this, the bombarding current is maintained steady, in spite of pressure variations, by a controller which operates by varying the heater voltage, and has been described previously.$^{(2)}$

Automatic operation. The apparatus can be operated that the zone-refining cycle is fully automatic. The catho traverses the specimen at slow speed, sweeping the molt zone over a set length and then returns to the start at h speed, with the bombarding power set to a low (non-melti value, and the cycle is repeated. The switching of emission current is done by the same switches which limit traverse (Fig. 4).

CONCLUSION

The apparatus has been found simple and efficien operation. In particular, the ability to raise and lower bottom chuck has proved extremely useful in correcting shape of a specimen during operation. It has been easy

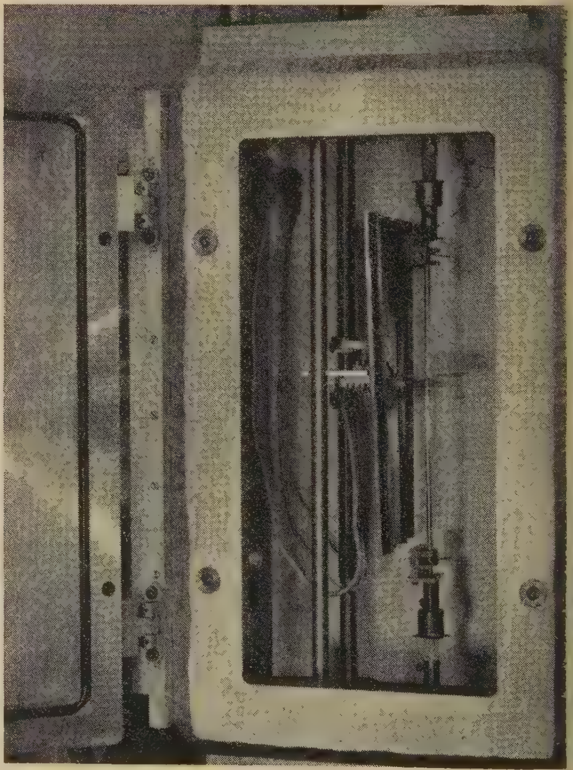

Fig. 6. Interior of apparatus

intain an operating vacuum in the 10^{-6} mb and, on asions, in the 10^{-7} mb range. The smallest specimen ned has been 0·060 in. in diameter, and this was done hout any difficulty at all, suggesting that smaller diameters ld be zoned. No investigation has yet been made to ertain the maximum diameter that can be zoned.

ACKNOWLEDGEMENTS

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nproved microbeam back-reflexion X-ray camera with arrangement for irradiating a pre-selected area

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An improved camera is described for use in conjunction with a microfocus X-ray tube. It has the advantages over previous cameras of being more rapid and precise in setting and of enabling much shorter exposure times to be used for X-ray beams of 10 to 50 μ in diameter.

e camera described in this note differs principally from other igns(1,2,3) in features which increase its accuracy for sitioning selected areas to be irradiated. The present nera was designed to locate reliably, for example, martensite tes, on the average 10 to 20 μ in diameter, in an X-ray um of approximately the same diameter.

n the past one of three methods has been utilized in order position the X-ray beam on a pre-selected area of the cimen:—

a) The area to be irradiated is selected under a microscope d its distance from a fixed small hole adjacent to the sample asured.(1) The X-ray beam is then located by means of small hole using a Geiger counter; displacement by the asured distance brings the selected area under the beam. e main disadvantage of this method is that the location of X-ray beam can be quite time-consuming.

b) The same pinhole is used to collimate both the light am and the X-ray beam, and thus the same area on the nple is irradiated by both beams.(4) Low-power optical croscopes have to be used and this places a limit on the curacy of positioning possible.

c) The X-ray beam is first located on a fluorescent crystal d viewed with a low power travelling microscope.(2,3) e microscope is adjusted so that the image of the crystal focused on a set of crosswires; the crystal is then replaced the sample, which is positioned so that it is also in focus on crosswires. Positioning of the microscope is tedious cause the fluorescent spot is too faint when viewed with a gh power objective (×40). With a low power objective 3) positioning is obviously not very precise.

Method (*a*) is potentially the most accurate and formed the sis of the present design. However, in place of a hole for point of reference, a set of wolfram crosswires, 0·13 mm diameter, was used. Another modification was the use of a gle pinhole instead of lead glass capillary to define the ray beam size. This was possible because the microfocus ray tube used had a focal spot only about 40 μ in diameter and consequently the divergence of the beam, defined by a pinhole at some distance from the focal spot, was very slight. The difficult procedure of alining a tubular collimator was thus eliminated.

The general arrangement of the apparatus on the Hilger microfocus X-ray unit is shown in Fig. 1. The apparatus is inclined at approximately 6 deg. to the horizontal and consists of three main parts: the pinhole assembly, the film cassette and the specimen stage with crosswires. Each part can be adjusted by sliding its mounting bracket along the X-ray tube or the vertical connecting tube, and fixed in position by tightening the bolts on the brackets.

The pinhole unit consists of a platinum foil about 0·1 mm thick and with a small hole in the centre, mounted on a brass washer with a ⅛ in. hole concentric with that in the foil. Three such units were available with hole sizes of 10, 25, and 50 μ in diameter in the platinum foil. A larger hole (about 100 μ) was produced in a brass disk by drilling. Lateral movement (i.e. perpendicular to the plane of the drawing) for alinement purposes was provided by fixing the pinhole unit on to a sliding plate as shown in the figure.

The position of the film cassette was adjusted so that it almost touched the pinhole assembly (not as shown in the exploded view in Fig. 1). The cassette can be adjusted so that its central hole permits unobstructed passage of the X-ray beam to the specimen or the crosswires. The film-to-specimen distance is normally set at 1 cm.

The specimen stage consists of the high-precision mechanical stage from a Cooke, Troughton and Simms "Nuclear Research Microscope" with two micrometer screws calibrated in units of 0·005 mm (about 0·0002 in.), and acting against the spring-loaded platforms of the stage. The backlash is less than half a division (2½ μ). The stage can be unscrewed from its bracket on the X-ray unit and screwed on to a bench microscope for determination of the relative co-ordinates of the crosswires and the specimen feature which is to be examined. At no time does the stage have to be inverted or even tilted more then 6 deg. from the horizontal. The bench microscope has an attachment for taking photographs if so desired. The specimen is mounted with Plasticine in the space adjacent to

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the crosswires so that its polished face is uppermost and accurately level with the crosswires.

A G–M counter is placed below the specimen stage to pick up the X-ray beam when locating the position of the crosswires. The counter is connected to a rate meter in order to observe the reduced beam intensity as the two wires of the crosswires passed in turn through the beam; the corresponding micrometer readings give the origin of co-ordinates for subsequent location of the selected specimen area.

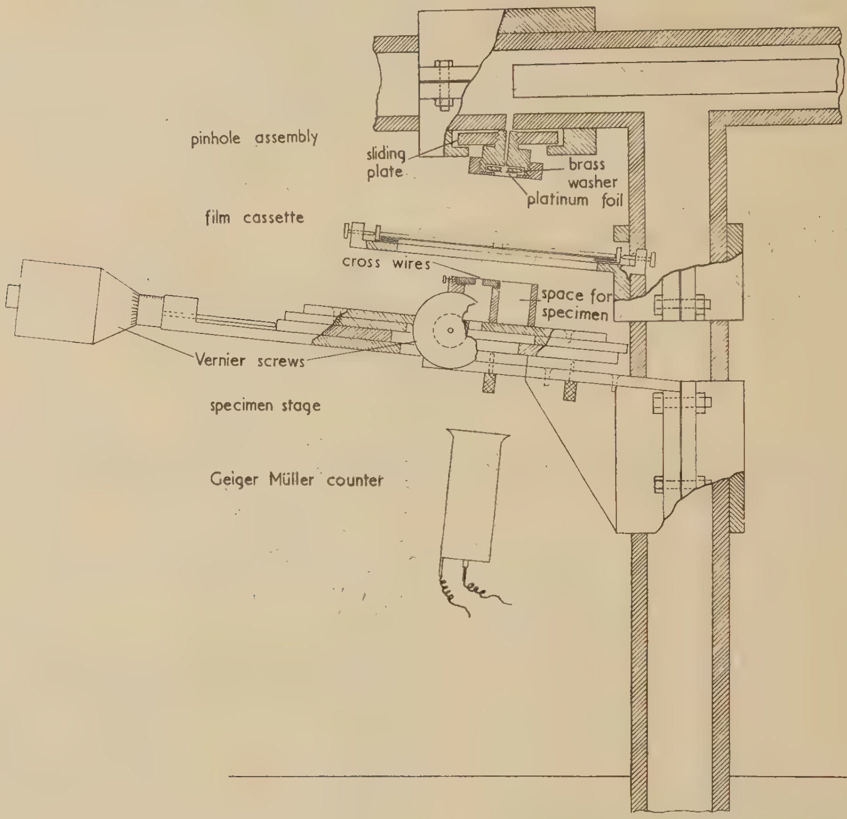

Fig. 1. Partly exploded view of camera assembly

The overall accuracy of the instrument was checked by using one of the pinhole units in place of a specimen, and a small piece of film (wrapped in light-proof paper) at the bottom of the space provided for the specimen. Since the thin platinum foil of the pinhole units permitted some X-rays to penetrate, a long time-exposure showed a small black dot representing the pinhole and a larger much lighter area representing the hole in the brass mounting washer of the second pinhole. If the focal spot in the X-ray tube, the pinhole unit in the assembly, and the second pinhole in the specimen position all line up perfectly, then only one black dot will be seen inside the lighter area on the photograph. If the alinement is in error, then two black dots will appear; the distance between the dots and their relative position determines the magnitude and direction of the error. Fig. 2 shows the result obtained with a 10 μ hole in the assembly and a 25 μ hole in the specimen position, when no particular care was taken to achieve optimum accuracy. The film from which the enlarged print in Fig. 2 was obtained was placed ¾ in. behind the second pinhole. The sharp dot is therefore due to the 25 μ hole; direct measurement on the film (under a microscope) gave a diameter of 53 μ for this dot and about 88 μ for the more diffuse dot, with a distance between the centres of about 39 μ. Geometrical construction of the X-ray beam paths indicated that this corresponded to a distance of 18 to 20 μ at the specimen surface. The size of the foc spot was also determined in this case, from the same co struction, to be approximately 100 μ.

When the separation between the centres of the dots on t film was less than about 25 μ (corresponding to a separati at the specimen surface of about 12 μ) trustworthy measur ments could no longer be made. Careful positioning ga results that fell within this range. Thus any errors due backlash and due to the fact that it was not possible to ha

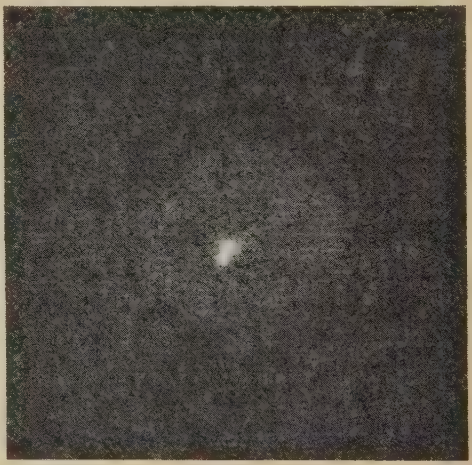

Fig. 2. Positive enlargement (×37) of photograph used for testing alinement of camera components

the two wires of the crosswires in the same plane (making necessary at a magnification of ×400 to refocus in going fro one wire to the other) were smaller than could be measure posure times with white radiation from a wolfram t operating at 50 kV, 400 μA and a specimen-to-film nce of 10 mm were, for an austenitic steel, about 2 to ising the 50 μ hole and of the order of 50 h using the hole.

e instrument has been successfully used to obtain the tation of individual martensite lamellae in steel(5) and rain orientation in iron, uranium and gallium phosphide. exposure times required with an X-ray beam of given eter were much shorter than with the original instru-(1); this is attributed to the very high brightness of the spot in a microfocus X-ray unit.

ACKNOWLEDGEMENTS

The platinum foils with the fine holes were obtained from Johnson Matthey Ltd. (London), Spinneret Department, through the kind co-operation of Mr. Windham.

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rsion-effusion apparatus for the study of vapour pressures of alloys

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A simple apparatus for the direct measurement of vapour pressures of metals by the torsional deflexion of an effusion cell is described. Results are given showing its use for the study of solid and liquid alloys. Its suitability for this purpose is discussed.

ion techniques, in which the rate of evaporation of a ance *in vacuo* is observed, have been widely used for neasurement of vapour pressures over metals and alloys.(1) t workers have used either the Langmuir method, in h a specimen of known surface area is employed, or the dsen method, where the rate of flow through a small e of known dimensions is measured. In either case, the ur pressure is calculated from the equation

$$p = \frac{m}{At}\left(\frac{2\pi RT}{M}\right)^{\frac{1}{2}} \qquad (1)$$

e p = the vapour pressure (atm)
m = mass of substance evaporated (g)
R = gas constant (cal/° C)
T = temperature (° K)
A = effective surface area of specimen (Langmuir) or orifice area (Knudsen) (cm^2)
t = evaporation time (s)
M = molecular weight of vapour.

less commonly used effusion method, originated by ner,(2) has been adopted by the authors for studies on s at elevated temperatures, although it had not pre-sly been used for this purpose.* In this, the pressure ted by vapour effusing from an orifice is measured directly. specimen is enclosed in an effusion cell suspended from e wire or fibre and the vapour allowed to stream out in rizontal direction from two eccentrically placed holes, exerting a torque. The angle through which the cell cts is observed and the vapour pressure is calculated the equation:

$$p = \frac{2\tau\alpha}{(a_1q_1 + a_2q_2)} \qquad (2)$$

e p = vapour pressure (dyn/cm^2)
τ = torsion constant of suspension (dyn cm/radian)
α = angle of deflexion (radians)
a_1 = cross-sectional area of hole 1 (cm^2)
a_2 = cross-sectional area of hole 2 (cm^2)
q_1 = horizontal distance of hole 1 from suspension (cm)
q_2 = horizontal distance of hole 2 from suspension (cm).

PREVIOUS WORK

The torsion method was first used by Volmer(2) for the measurement of the vapour pressures of various organic solids at near room temperature. He employed a brass effusion cell, suspended from a tungsten wire and enclosed within a glass vacuum chamber; heating was by means of a water bath. Neumann and Völker(4) used a similar apparatus, but with a quartz torsion fibre, to measure the vapour pressures of benzophenone, mercury and potassium at temperatures up to 200° C, whilst Neumann and Lichtenberg(5) measured the vapour pressure of selenium at still higher temperatures. Again with a similar apparatus, but using quartz effusion cells, Barrow and others(6) studied the heat of sublimation of zinc at temperatures up to 400° C, while various Japanese workers have made measurements of the vapour pressures and atomicities of selenium,(7) tellurium,(8) antimony(9) and bismuth.(10)

Using quartz, alumina or graphite cells suspended from tungsten wire inside a metal vacuum chamber, Wessel(11) extended the range of application of the method up to 1500° C and made measurements on cadmium, silver and iron; heating was effected by passing a direct current through a graphite tube immediately surrounding the cell. More recently, Searcy and Freeman(12) designed an apparatus for use up to 1900° C. They employed a graphite effusion cell hung from a tungsten wire within a Pyrex vacuum chamber. Induction heating was used, but this necessitated corrections for the rotational effect of the field on the cell. The vapour pressures and vapour atomicities of tin(12) and germanium(13) were studied.

EXPERIMENTAL DETAILS

The present apparatus is shown diagrammatically in Fig. 1. It consists essentially of a torsion system enclosed within a vertical vacuum chamber. The upper section of the vacuum

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Since the present work was started, the use of the technique he study of molecular species in the vapour of potassium gams at temperatures below 300° C has been reported.(3)

envelope is a brass tube, 40 cm in length and 6 cm in diameter, flanged at each end. A side arm, through which the system is evacuated, is fitted near the lower end and immediately opposite is situated a second short tube fitted with a 4 cm diameter plate-glass window. Alongside are glass-to-metal seals through which thermocouple wires pass. The lower half of the chamber consists of a Vitreosil tube, 45 cm long and 5·25 cm in bore, sealed at the lower end. The top is waxed by means of Picien wax into a 10 cm diameter brass plate. This is then bolted beneath the upper section, a vacuum-tight seal being provided by a 6·83 cm diameter O-ring. The whole joint is water cooled. The vacuum chamber is closed at the upper end by a brass plate resting freely on an O-ring. The torsion system is suspended from the centre of this plate by means of a small pin chuck.

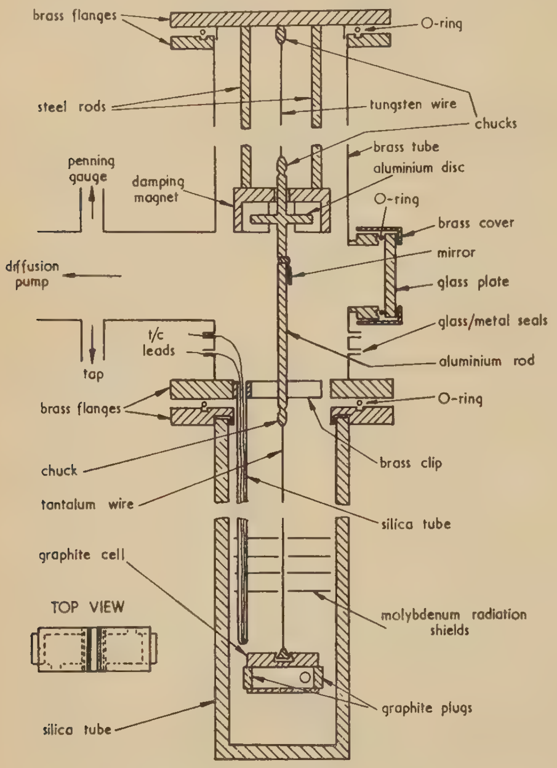

Fig. 1. Torsion effusion apparatus

The chamber is evacuated by the use of a 2 in. Edwards "Speedivac" oil-diffusion pump connected, via a baffle valve, directly to the side arm. It is backed by an Edwards single-stage rotary pump. Vacuums of the order of 5×10^{-6} mm of mercury are obtained. Measurements of the vacuum are normally made by means of a Penning gauge with a modified meter calibrated to give accurate readings down to 10^{-6} mm of mercury.

The torsion system, which is based on that used by Searcy and Freeman,(12) consists of four parts. The suspension is a thoroughly annealed tungsten wire, 25 cm long and 0·005 cm in diameter. This hangs from the small chuck and to it, by means of a second chuck, is fixed an aluminium rod. The rod is 15 cm in length and 0·6 cm in diameter and carries a concentric aluminium disk, 3 cm in diameter and 0·6 cm thick, at a point about 4 cm from the upper end. Surrounding the disk is a damping magnet consisting of an "Alnico" bar with two cylindrical pole pieces; this is rigidly suspended from the head plate. A galvanometer mirror, 1 cm in diameter and of focal length 1 m, is mounted on the rod at a point oppo the vacuum chamber window. To the bottom of the rod means of another chuck, is attached a rigid and stra tantalum wire 40 cm long and 0·05 cm in diameter. effusion cell is carried at the lower end of this wire. Det of the cell and the method of attachment are shown in Fig

A small, carefully machined graphite block is fitted to tantalum wire; the wire fits tightly through a vertical h in the block and the end, bent through 90 deg., fits int groove machined in its underside so locking the block position. The block fits into a matching keyway in upper side of the effusion cell. The cell is thus loca accurately but may be easily removed and replaced with interference with the remainder of the torsion system.

The cell is made from a rectangular block of Morgan E graphite 3·8 cm long, 2·5 cm in height and 1·75 cm th A 1·4 cm diameter hole is drilled throughout its length, centre being approximately 0·9 cm from the lower f The ends of the hole are closed with tightly fitting grap plugs. Two orifices are drilled in the vertical faces; vari diameters (0·11 cm, 0·17 cm, 0·31 cm) are employed these according to the magnitude of the vapour pressure to studied. The tapered keyway is machined transversely a the upper face of the cell. To reduce the length of the orif and thereby the experimental correction factors, the side fa are finally carefully polished by hand on a fine abra until a wall thickness of about 0·5 mm remains. Ori areas are measured from magnified (×100) images projec on to a scaled screen on a Vickers projection microscope counting squares, the areas can be determined to an accur of $\pm 10^{-5}$ cm^2. Orifice lengths and their distances from axis of rotation of the cell are measured by means o travelling microscope. These dimensions are corrected the effect of expansion at each experimental temperatu using a value of coefficient of linear expansion o $7{\cdot}86 \times 10^{-6}$. Before use, the graphite cells are baked several hours *in vacuo* at about 1000° C to remove contamination.

For present studies, where the maximum required tempe ture does not exceed approximately 1000° C, the cell heated by a simple non-inductively wound resistance furna so avoiding the rotational corrections necessary with hi frequency heating. The furnace is 30 cm long and 7·5 in diameter and is fitted with a stainless-steel liner wh provides a central uniform-temperature zone extending o approximately 8 cm around the cell. Power is supplied fr a "Variac" auto-transformer and the temperature is c trolled by a chromel-alumel thermocouple and an Et "Transitrol" controller, switching an auxiliary resistance series with the furnace winding. Control to ±1° C obtained. The furnace is fitted with runners and coun balance weights in a frame and is moved vertically to surrou the lower half of the vacuum chamber. To prevent operation and other external vibrations from disturbing torsion system the vacuum chamber is carried on a separ frame standing on anti-vibration mountings. Flexible rub connexions are used between the backing and diffus pumps to minimize the transmission of rotary-pu vibrations.

Cell temperatures are measured by means of a pla num/platinum-(13%)-rhodium thermocouple located wit the vacuum chamber with the tip 5 mm from the effus cell. The couple is enclosed in a thin-walled silica sheath prevent contamination by effusing vapour. The she which is held in position by a spring clip carries five mol denum radiation shields which can be rotated aside w the suspension to enter. The temperatures observed ı the above couple are corrected to give the true cell perature. The correction factors, which are small, are ained from a preliminary experiment in which a second mocouple is placed within the effusion cell and normal erimental conditions are exactly reproduced.

otation of the cell is measured from the movement of a t beam reflected from the mirror on the aluminium rod. lexions of the beam are observed on a 2 m scale bent to n the arc of a circle of 1 m radius from the mirror. The e is calibrated by rotating the head of the suspension ough known angles measured from a protractor fitted on head plate. The total span of the scale is 26·5 deg. and exions can be estimated to an accuracy of $\pm\frac{1}{2}$ min. ger rotations are measured by backing-off part of the exion by turning the head plate by a suitable amount ing the run. Before and after each experiment, the ion constant of the suspension is determined from ional-periodicity measurements; for this purpose the sion cell is replaced by a cylinder of known moment of tia and the damping magnet is raised clear of the minium disk.

lloys are prepared by melting and chill casting. When the iid range only is to be investigated, pieces of the cast ot are used as the specimen. Where measurements are be made on alloys in the solid state, the ingots are first roughly homogenized by annealing in evacuated capsules r which they are machined to provide turnings. These the most suitable form of solid specimen because they e a large surface-to-volume ratio and will remain loosely ked so ensuring the maximum effective free surface. After efully cleaning and drying, samples are loaded into the ision cell which is then fixed to the torsion system. The uum chamber is closed and evacuated and the furnace is sed into position. Out-gassing of the cell and chamber lls are helped by gently heating, but the furnace temperature naintained below that at which significant evaporation can ur from the specimen. When a vacuum of 10^{-6} mm of rcury is achieved the torsion system "zero point" is noted. e furnace controller is re-set to the desired experimental nperature and the power input adjusted to ensure rapid ting. When the cell temperature is steady, the rotation the cell is measured. Only when this rises to a steady value l maintains this over a period of time can it be considered t the equilibrium vapour pressure is being observed. The nperature is then adjusted and the new deflexion noted. mperatures are selected at random to check that equiliium is being obtained. When observations are complete, furnace is lowered from around the chamber and the ecimens rapidly cooled. The "zero point" is checked for roducibility. A sample of the specimen is analysed to ermine the extent of the change of composition during run; this is not allowed to exceed 0·5 atomic per cent in individual run.

EXPERIMENTAL RESULTS

The relation between cell deflexion and pressure given in ıation (2) represents the idealized case where the cell fices are of zero length. In practice, the pressures are culated using the modified relation

$$p = \frac{2\tau\alpha}{(a_1q_1f_1 + a_2q_2f_2)} \tag{3}$$

ere the factors f_1 and f_2 correct for the effect of the finite gth of the orifices and are functions of the angular distribution of the effusing molecules. Using Clausing's(10) calculation for this angular distribution, Freeman and Searcy(11) have shown that for orifice dimensions in the range $0 \leqslant L/r \leqslant 2$ (where L and r are the orifice length and radius respectively), values of f can be satisfactorily obtained from the equation:

$$\frac{1}{f} = 0\cdot0147\left(\frac{L}{r}\right)^2 + 0\cdot349\left(\frac{L}{r}\right) + 0\cdot9982.$$

This relation is employed in the present calculations.

Examples of results obtained for solid and liquid alloys and for a pure metal are shown in Fig. 2. The vapour pressure of pure liquid bismuth confirms most of the previous work. The results for the 39·3 atomic per cent bismuth alloy when combined with those for pure bismuth give thermodynamic-activity values indicating a negative deviation from ideality. Although no independent measurements are available for comparison, the observed activity value at 1000° K agrees closely with that computed from the silver-bismuth equilibrium diagram. Because of the much lower liquidus temperature at the higher bismuth content, it is not possible to obtain equally reliable computed values for comparison with the experimental results for the 65 atomic per cent bismuth alloy. However, the experimental and more-approximate computed values do both indicate similar positive deviations from ideality at this composition. In the case of the solid silver–magnesium alloys there are again no independent measurements available for the temperature range investigated. The present results indicate strong negative deviations from ideality in the activities of magnesium at both compositions. The magnitude of the deviation is consistent with that observed at lower temperatures in galvanic cell measurements.(16)

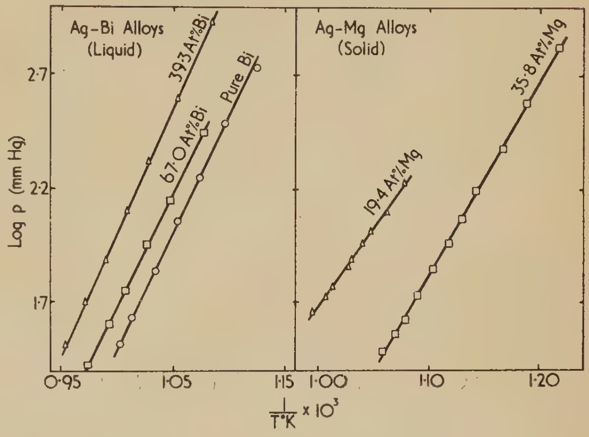

Fig. 2. Results for solid and liquid alloys and for a pure metal

DISCUSSION

Results suggest that the torsion-effusion technique will prove useful for the investigation of the vapour pressures of liquid or solid alloys. Absolute measurements are practicable over the range 10^{-2}–10^{-5} mm of mercury; at the extreme low-pressure end of the range the accuracy is estimated to be $\pm 10\%$ but at higher pressures results should be accurate to $\pm 1\%$. The range of application is similar to that of the Knudsen method since the fundamental requirements are similar.(17) The dimensions of the orifices must ensure molecular streaming for the equations used to be valid. Although not so precise in the lowest pressure ranges, the method is more rapid than even the most refined Knudsen technique because it provides an almost instantaneous measurement of the pressure at each temperature. Thus, possible changes in alloy composition during an experiment are minimized. Furthermore, since the pressure is observed continuously the occurence of anomalous values, because of general or local impoverishment or superficial contamination, are readily detectable.

Significant values can only be obtained if the alloy is able to establish its equilibrium vapour pressure within the cell. To minimize composition changes, the rate of effusion from the cell should be low while, to ensure that the equilibrium pressure is maintained in the cell, the possible rate of evaporation from the specimen surface must be large compared with this. Thus the orifice area is made as small as is compatible with accurately observable deflexions, and the ratio of specimen area to orifice area is made as large as possible. Equilibrium between the surface and the interior of the specimen must also be ensured. To sustain the required rate of evaporation and prevent surface impoverishment, temperatures must be adequate to provide sufficiently rapid diffusion of the volatile component to the specimen surface. This is also assisted by the use of a specimen of large surface-to-volume ratio.

A great advantage of the method is that it gives an unambiguous and absolute measure of the pressure, as the torque exerted is directly observed. Unlike other effusion techniques, a knowledge of the molecular weight of the effusing vapour is unnecessary. The technique is particularly suitable therefore for measurements involving complex vapours where the atomicity is variable or not well established—for example, alloys of bismuth or antimony. If desired, the atomicity can be determined by combining torsion-effusion with Knudsen measurements.$^{(9)}$

ACKNOWLEDGEMENTS

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Direct stress machine for combined fatigue and creep testing

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The report describes the modifications introduced to a commercial creep testing machine so that tests under combined fatigue and creep conditions can be carried out. Results are given illustrating the performance of the converted machine. Limitations and further modifications are briefly discussed. The combined testing machine is now commercially available.

1. INTRODUCTION

There has been a growing awareness in recent years of the inadequacy of tests and standards which give isolated indices for the mechanical behaviour of metals and alloys. In service, components are subjected to stresses and conditions which may be quite different from the idealized ones in a laboratory test. It is now clear that processes of deformation, fracture, corrosion, etc., do "interact" in a complex manner and the overall behaviour cannot be predicted by a simple superposition of test results.

Tests have been carried out recently, mainly in the United States, to establish the behaviour of certain heat resisting alloys under conditions of combined fatigue and creep. The testing equipment used can be divided into two classes; modified fatigue machines and specially constructed machines, as discussed in a recent review.* A fatigue machine capab of exerting a mean stress and accommodating creep strain suitable for this type of work. These machines are genera expensive and are normally overloaded with problems of pu fatigue. Creep machines, on the other hand, are less cost and numerous types are available in large numbers in mo laboratories.

The present report describes the modification† of a inexpensive commercially available creep machine into combined fatigue/creep machine. Creep stresses can applied up to 2000 kg cm^{-2}: and fatigue stress amplitudes u to 500; the fatigue frequency ranging between 200 ar 3000 cycles per minute. The main advantages of the prese ified machine are the comparatively low cost and plicity of operation. In a creep laboratory, a proportion vailable machines can be modified in a short time, thus ening the scope of testing capabilities of the laboratory. he combined fatigue/creep testing machine is now being ufactured by Messrs. Samuel Denison and Son Ltd., slet Foundry, Leeds, 10.

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* Evershed, A. V. BISRA Report P/14/58.

† The subject of Brit. Pat. appln. No. 7134/59.

2. PRINCIPLE AND MODIFICATION

ever type creep machines are generally of a robust con- ction and the lever itself is of large inertia. If the lever ade to vibrate during a creep test it forms a mass-spring em with the specimen and the weights. If the vibration ntroduced near the resonance frequency of the system, e amplitudes of fatigue stresses can be superimposed on initial static stress.

he machine used in the present work is the Miniature ison 3/4 ton machine and the vibration was introduced means of a 120 W electromagnetic vibrator. This was en from a power oscillator of a wide frequency range, to 24 × 10^5 c/min. However, the vibrator can be en direct from the mains supply, but in this case the tests ld be restricted to the mains frequency.

he vibrator was mounted on a rigid plate fixed to the base he machine by four pillars as shown in Fig. 1. The rator plunger was jointed to the free end of the lever by ns of a hinge which allows for the small rotations of the r. It is important to operate the vibrator about its mean r. It is important to operate the vibrator about its mean ition and during a creep test the lever is brought back to orizontal position at regular intervals. This readjustment be carried out without interfering with the progress of experiment by lowering the straining screw by means of setting swapes shown in the illustration.

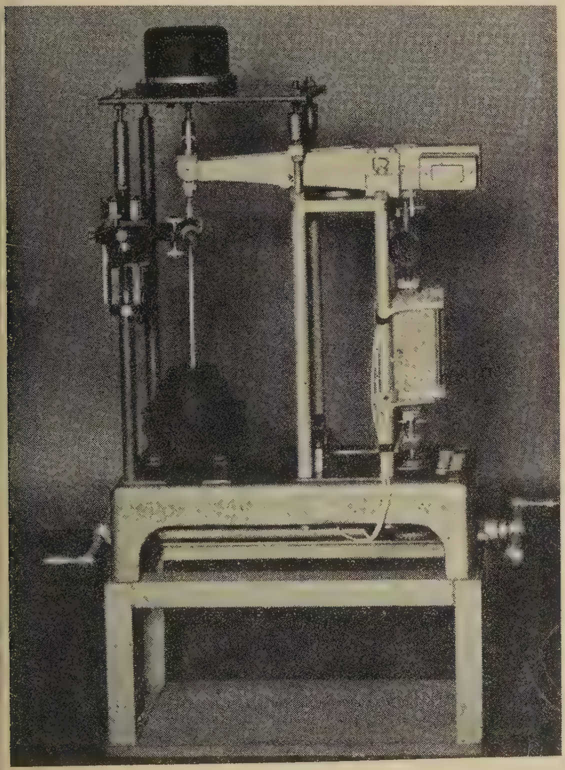


Fig. 1. The fatigue-creep machine

3. CALIBRATION AND PERFORMANCE

The fatigue stress amplitude is controlled by the amplitude of the vibration of the system. For the same mechanical constants of the systems, i.e. for the same resonance frequency, the fatigue amplitude can be controlled by varying the amplitude of the force imposed by the vibrator. The fatigue amplitude is also dependent on the frequency of the vibrator force; larger amplitudes can be obtained as the frequency approaches resonance.

A series of curves are given in Fig. 2, which show the variation of the fatigue amplitude with various current inputs to the vibrator, for the frequency range 600 to 1800 c/min, and a creep force of 75 kg. The fatigue stress amplitude was measured by means of a ring inserted in series with the specimen. Strain gauges were cemented to the ring which was calibrated statically. The change in resistance of the strain gauges $\Delta R/R$ was measured by a manually operated bridge. For dynamic measurements, $\Delta R/R$ was obtained for the peak-to-peak values of the force. In Fig. 2, however, the fatigue force amplitude is shown, and it can be seen that this varies linearly with vibrator current for all but the resonance frequency. The slopes of the lines of Fig. 2 are plotted against frequency in Fig. 3, which is in effect a response curve. Since a change in the dead weight alters the dynamic characteristic of the system, two additional response curves for 50 and 100 kg creep force are shown in Fig. 3.

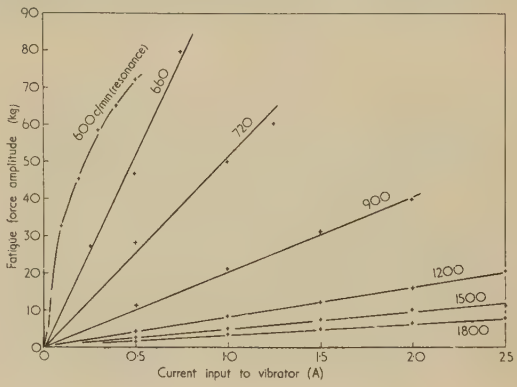


Fig. 2. Variation of vibrator input with resultant fatigue force amplitude for various frequencies

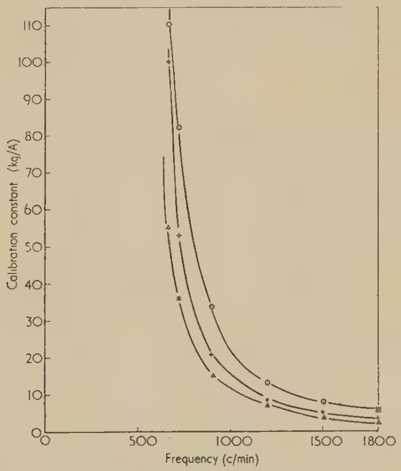
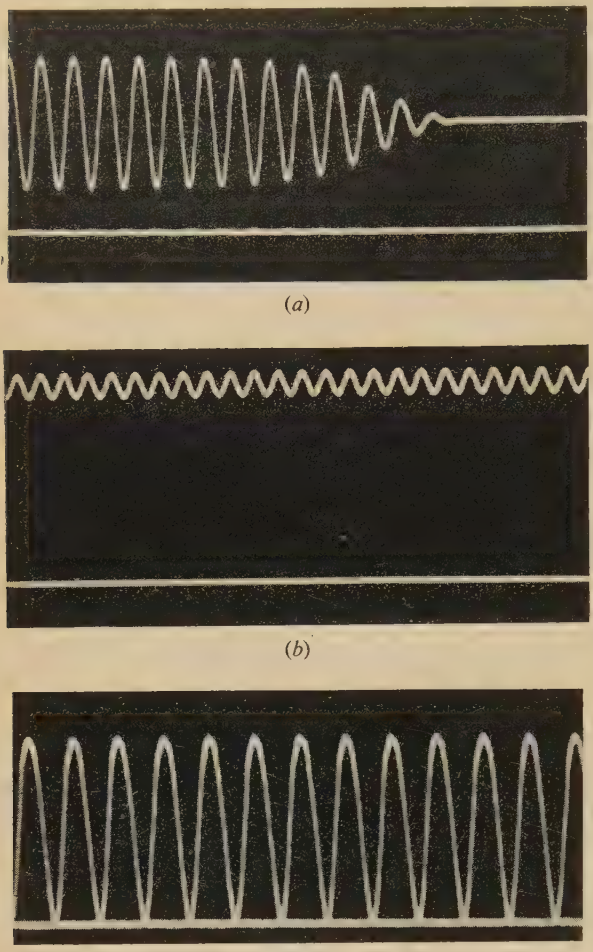


Fig. 3. Response curves

Creep force: ⊙ 50 kg; + 75 kg; △ 100 kg.

A series of oscilloscope traces obtained from the strain-gauge bridge are shown in Fig. 4 [(*a*)–(*c*)] to illustrate the performance of the machine. In (*a*) the building-up period of the fatigue force is shown. Small fatigue forces can be introduced (*b*), and the amplitude can be increased to a value equal to the creep force as illustrated in (*c*).


(*a*)

(*b*)

(*c*)

Fig. 4. Force traces: (*a*) "building-up" period; (*b*) small fatigue stress; (*c*) fatigue stress amplitude equal to creep stress

4. AN EXPERIMENT WITH COPPER AT 450° C

The experiment described below illustrates the performance of the converted machine and demonstrates the importance of testing under combined fatigue and creep conditions.

A copper specimen was stressed in a static creep test at a stress of 625 kg cm^{-2}: and a temperature of 450° C. The creep strain was determined to $\pm 5 \cdot 10^{-6}$ by means of a differential transformer type extensometer. The steady state was reached giving a creep rate of 0·004 17%/min, as shown in part *AB* of Fig. 5. A fatigue stress of 62 kg cm^{-2} was then superimposed at a frequency of 1200 c/min. Although this amplitude is only 10% of the static component it can be seen (part *BC*) that the creep rate increased to 0·0325%/min, a factor of 8. The fatig amplitude was then doubled and part *CD* of the graph sho that the creep rate was increased by the same ratio. T fatigue stress was then removed; this resulted in a decre in the creep rate to 0·001 67%/min, which is only 0·4 of t original static creep rate.

It is not possible to draw any definite conclusions from single experiment, but the results given above suggest t fatigue stresses soften the specimen if superimposed on static stress. This softening effect is reversed if the fatig stress is removed. It appears that the structural chan induced while a fatigue stress is applied, encourage the fl of the metal probably due to vacancy generation in the gra or grain boundary sliding. These structural changes, ho ever, appear to act as obstacles to further static flow.

5. LIMITATIONS AND FURTHER MODIFICATION

The performance of the machine in its present fo satisfies the requirements of the experiments about to commenced. However, certain limitations are discuss below, together with some suggested modifications.

(1) The machine is not capable of exerting a compress force on the specimen since the joints between the lever one hand and the straining and loading rods on the ot are designed in the original machine to sustain a force one direction only, producing a tensile force in the specim If the input current to the vibrator exceeds the value requi to reach the state illustrated in Fig. 4(*c*), a distorted cy force is then produced as shown in Fig. 6. At prese therefore, the creep stress must be slightly greater than t fatigue stress amplitude.

This limitation may be overcome by replacing the join with ones capable of withstanding both tensile and co pressive forces. Since the lever is statically balanced t modification would have the added advantage of renderi the machine suitable for completely reversed fatigue testi This is essential if the effect of small creep strains on t fatigue behaviour is to be investigated.

(2) The vibration of the system may produce an accelerati on the weights equal to that of gravity, and this cau bouncing of the weights, thus distorting the force wavefo on the specimen. This limitation is present only at high frequencies or when large fatigue amplitudes are requi It can be overcome by rigidly fixing the weights to the loadi rod, provided the joint connecting it to the lever is of t tension-compression type. This difficulty does not arise,

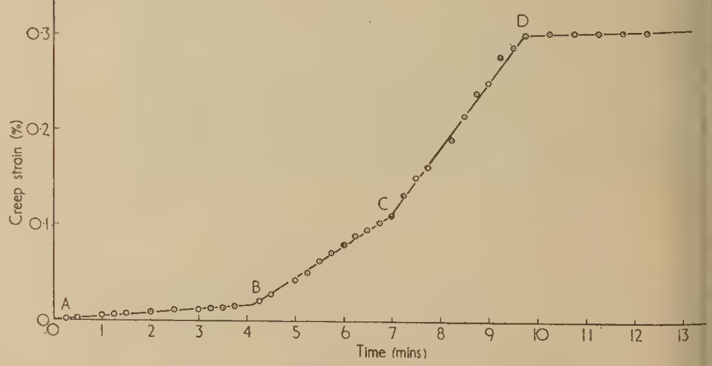


Fig. 5. An experiment with copper

AB, creep stress only; *B*, fatigue stress superimposed; *C*, fatigue stre increased; *D*, fatigue stress removed.

e, if the static component of the stress is applied by means, e.g. a spring system. In this case, the lever d have to be continuously readjusted to maintain a ant creep load on the specimen.

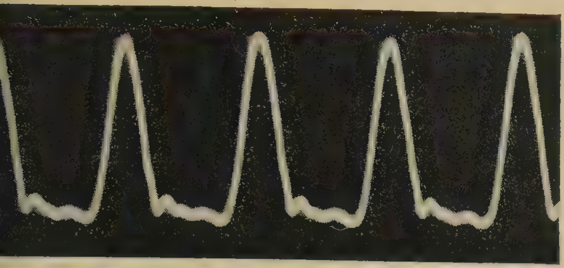


Fig. 6. Vibrator input increased beyond case in Fig. 4 (*c*)

The useful frequency range of the present modified ine is 200 to 3000 c/min, which is adequate for the nt programme. However, higher frequencies can be investigated by the use of a more powerful vibrator. The resonance frequency of the machine can be increased by using spring loading or by employing a lighter lever.

For frequencies below 200 c/min, it is not possible to use the commercial types of power oscillators. For this range of frequency the vibrator can be energized by a slowly cycling direct current. A successful attempt has been made to achieve this by means of a slowly driven potentiometer.

6. CONCLUSIONS

The above shows that it is not necessary to construct special machines for combined fatigue and creep testing. Lever-type creep machines can be converted cheaply and a wide range of experimental parameters can be covered. The necessary design details of the modifications are described in the report.

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TIM; a brushless generating magnetometer

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TIM (the turbo-inductor magnetometer) is an air-driven generating magnetometer which uses inductive output to avoid brushes and slip rings. The resulting mechanical simplicity allows TIM to be made very small while the high rotational speed, which is possible because there are no brushes, makes TIM quite sensitive. It is most suitable for measuring static or very nearly static magnetic fields. The output is an audiofrequency signal, and the accuracy depends chiefly on how accurately the amplitude and frequency of that signal are measured.

turbo-inductor magnetometer (TIM) is a simple device he rough measurement of magnetic fields. Even small els of TIM are quite sensitive; the example sketched in 1 will enter a 5 mm hole and yet measure fields below 1 G. n measure strongly inhomogeneous fields, and the volume which the field is averaged is small. Its operation is ely classical and what difficulties there are are mostly ianical.

principle it is an air-driven, iron-free alternator, the d" of which is the magnetic field being measured. It ists of a fixed pick-up coil inside which is a disk-shaped ctor. A jet of air spins this disk about one of its diameters, ıxis of rotation being at right angles to the axis of the coil. disk spins at the order of 50 000 rev/min.

ıe magnetic field which is being measured induces latory circulating currents in the spinning disk. These ents in turn induce in the pick-up coil an alternating ıge which is proportional to the original magnetic field. inductive output is naturally much smaller than could be ined with a wound rotor and brushes and slip rings, but h of this loss is regained by the very high rotation speed h the absence of brushes makes possible.

ıe volume of field which TIM averages is only that swept by the inductor disk. In the model shown in Fig. 1 this out 4 mm^3.

THEORY

o make the analysis easier consider an inductor in the ı of a thin ring.

eferring to Figs. 1 and 2:

H = the magnetic field;
β = the angle between H and the axis of inductor rotation;
$H_\perp$ = the component of magnetic field perpendicular to the axis of inductor rotation;
ϕ = the angle between H and the axis of the pick-up coil;
A = the area of the ring inductor;
F = the flux linking this area;
E = the induced potential difference in the ring;
I = the current in the ring;
ρ = the resistance of the ring;
L = the self-inductance of the ring;
E_{coil} = the induced potential in the pick-up coil;

then $F = H_\perp A \cos(\omega t - \phi)$

for only the component of H perpendicular to the inductor axis of rotation can link the inductor. In terms of H itself,

$$F = HA\cos(\omega t - \phi)\sin\beta$$
$$E = -\dot{F} = +HA\omega\sin(\omega t - \phi)\sin\beta$$

Since $E = I\rho + L\dot{I}$, it can be shown that

$$I = \frac{HA}{\rho}\,\frac{\omega}{\sqrt{\{1+(L\omega/\rho)^2\}}}\sin(\omega t - \phi - \alpha)\sin\beta \qquad (1)$$

where α is the phase lag caused by the self-inductance of the ring, and is given by

$$\tan\alpha = \omega L/\rho \qquad (2)$$

Equation (1) shows that the induced currents in the inductor are at the first harmonic of the rotation frequency, (following the convention that the "first harmonic" implies the "fundamental" frequency and the "second harmonic" implies twice that frequency). With regard to the pick-up coil the inductor is a rotating magnet, the strength of which varies sinusoidally as it rotates. The phase of this variation relative to the inductor rotation depends on the direction of H. The induced voltage in the coil depends on the rate of change of that component of the magnetic field of the inductor which is parallel to the coil axis. If L_m is the mutual inductance of the inductor and coil when their axes are parallel then

$$E_{coil} = (d/dt)(IL_m \cos \omega t) \qquad (3)$$

or

$$E_{coil} = \frac{L_m HA}{\rho} \frac{\omega^2}{\sqrt{\{1 + (L\omega/\rho)^2\}}} \cos(2\omega t - \phi - \alpha) \sin\beta \qquad (4)$$

The output is thus independent in amplitude, though not in phase, of the angle ϕ. This, coupled with the sin β dependence on the third dimension, gives a sensitivity pattern in the form of a closed-up torus as shown in Fig. 1. The output is at twice the frequency of rotation and, as $\omega L/\rho$ is usually less than 0·5, it is approximately proportional to ω^2. Here it has been assumed that the mutual inductance between the inductor and the pick-up coil is proportional to the cosine of the angle between them; this will be so in practice if the inductor is small and the pick-up coil is either long or split like a Helmholtz pair.

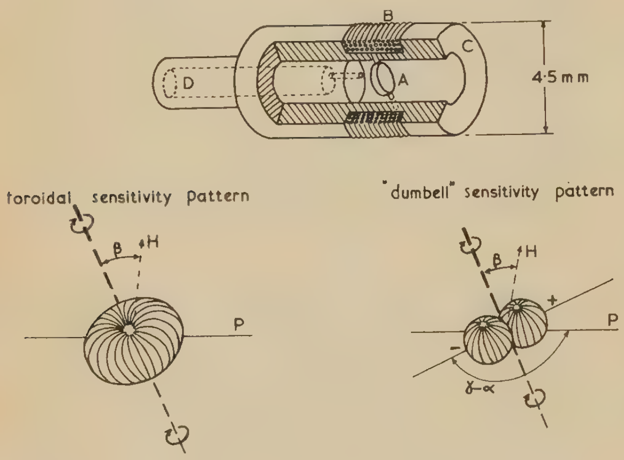


Fig. 1. A small model of TIM, the toroidal sensitivity pattern of ordinary models of TIM and the dumb-bell sensitivity pattern of most other instruments and of the phase-gated TIM

A, copper rotor on manganin axle; *B*, pick-up coil, 222 turns No. 46 copper wire; *C*, polythene stator body; *D*, compressed air pipe with nozzle.

A measurement of magnetic field entails, in general, the measurement of both the amplitude and the frequency of the output signal. While the sensitivity can, in principle, be calculated absolutely, it is easier to calibrate the instrument in a known field at a particular value of inductor revolutions per minute. For the model shown in Fig. 1, the calculated sensitivity at 92 000 rev/min is 0·007 mV/G into an infinite impedance, while an experimental calibration gave 0·0068 mV/G. This agreement is far better than the estimates of L and L_m; however it gives some confidence in the further estimation of $\omega L/\rho$ as 0·33 at 92 000 rev/min. Measurement of sensitivity as a function of ω showed no noticeable deviation from square law. However, even at the highest speed (120 000 rev/min) $\omega L/\rho$ is only 0·45 and the predicted deviation from square law is only 10%, which may well have been masked by imperfect amplifier characteristics. While a sensitivity of 0·007 mV/G seems small, it re represents considerable power because the pick-up resistance is only 16 Ω.

This analysis does not consider the reaction of current the pick-up coil on those in the inductor. The couplin sufficiently weak so this is a fair approximation. In model shown in Fig. 1, only about one-sixth of the induc flux links the pick-up coil. In any case, provided that pick-up coil is connected to a linear load, the output volt will still be a linear function of H.

Varying the temperature of the inductor changes its re tance, and thus the sensitivity of the instrument, so readi should be corrected for changes in ambient temperature. seems probable that the inductor is adequately air-cooled that temperature rise from eddy current losses is negligi however this point has not been investigated.

CONSTRUCTION

The only constructional difficulties result from TIM's sm size. In the model shown in Fig. 1 the inductor rotates o stationary axle. Unless this bearing is oiled every few minu it will chatter, because both the diameter of the axle and bearing clearances are too large compared with the size of rotor. In larger magnetometers both these factors improved and the rotor will spin for hours without attenti

The body is of insulating material, so that it does not fo a short circuit which would shield the pick-up coil from field of the inductor. Naturally, no magnetic material used.

For low magnetic fields, solid copper or alumini inductors are ideal as they give the biggest signal; howe for values of H over 100 G, eddy currents—the very curre used to measure H—become too large and slow the ro unless it is made more resistive.

One of the nicest features of TIM is just how crudel can be made and still produce useful results. The first mo which was only 1·5 cm in outside diameter, was made by amateur mechanic in two hours.

OPERATION

A transformer of the kind used with dynamic micropho is used to match the pick-up coil to an audio-amplifier. output is displayed on an oscilloscope which allows measurement of both amplitude and frequency. In practi with a well-regulated 15 lb/in.^{2} air supply, the bigger magne meters run at a sufficiently constant speed so that the freque measurement can be omitted whenever 5–10% accuracy good enough.

The oscilloscope display also allows mains freque pick-up to be recognized and rejected. Inevitably, TIM more sensitive to a.c. than to d.c. magnetic fields; a.c. fie are picked up by the coil directly, while d.c. fields are detec by the agency of the inductor, which is small and coup only weakly to the coil. Tuning of the amplifier, wh would normally solve such a problem as well as improv the signal/noise ratio, cannot be pushed very far becaus TIM's unavoidable speed variation.

This a.c. pick-up could also be reduced by the use of buck coils in series with the pick-up coil, connected so that one s the ambient H with equal but reversed flux linkage. Th coils should be farther away from the rotor than the pick coils and would thus leave the desired signal uncancelled. the absence of such coils, it is this search-coil effect wh makes TIM unsuitable for measuring time-varying values H. The difficulty is that the desired inductor signal is th erimposed on an enormous low-frequency signal, which ' well block the amplifier channel.

'he toroidal sensitivity pattern has several advantages over more usual dumb-bell pattern. Finding the direction of field is a null measurement (rather than a search for a ximum), for it is given by the direction of the inductor axis otation when there is zero output. The magnitude also nore easily found, because the maximum reading can be nd by rotation of the instrument about one axis only. ilarly, space limitations are less serious, for TIM can be riented with complete freedom about the axis of inductor ation. On the other hand, not to be able to specify the se of field is sometimes inconvenient. Also, field comients cannot be measured directly; at least, not without king TIM more complex. The measurement of a single nponent will be dealt with first.

'hase-gated output. If the magnetometer can be made to duce a phase signal at the 2ω frequency, and this is used to the output during the intervals 2δ from $\omega t = \gamma - \delta$ to

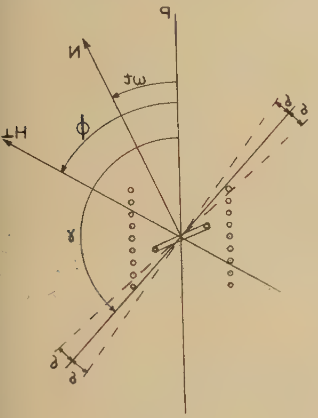


Fig. 2. Simplified TIM for analysis. The axis of inductor rotation is normal to the plane of the paper

$= \gamma + \delta$ and from $\omega t = \pi + \gamma - \delta$ to $\omega t = \pi + \gamma + \delta$ l so on, (see Fig. 2) then equation (4) shows that the average put voltage is given by

$$= \frac{\omega}{\pi}\int_{\omega t=\gamma-\delta}^{\omega t=\gamma+\delta} \frac{L_m HA}{\rho}\frac{\omega^2}{\sqrt{\{1+(\omega L/\rho)^2\}}}\cos(2\omega t-\phi-\alpha)\sin\beta dt$$

$$= \frac{1}{\pi}\frac{L_m HA}{\rho}\frac{\omega^2}{\sqrt{\{1+(\omega L/\rho)^2\}}}\cos(2\gamma-\phi-\alpha)\sin\beta\sin 2\delta \qquad (5)$$

'he cosine factor means that the sensitivity pattern is now more familiar dumb-bell shape, with positive output in lobe and negative output in the other (Fig. 1), so TIM v measures a single component. Phase gating also has the rantage of discriminating against both amplifier noise and pick-up.

Jnfortunately, obtaining a phase signal from an air-driven gnetometer is difficult. For sensing the position of the or a capacitative pick-up was used in which the varying acity between the rotor and a charged probe affected the ential of the latter; this worked, though not too well. ere was some disturbance by charges on the insulating ly in places which could be affected by the spinning rotor. art from that, the method requires a second amplifier nnel for handling the phase signal, as well as an electronic e.

f one only wants to find the direction of the field (plus, of rse, its magnitude) and is not interested in component asurement there is a far simpler method.

Twin-winding TIM. If the inductor disk is tipped so that its plane no longer includes the axle, as shown in Fig. 3, equation (1) for the circulating currents in the disk is replaced by equation (6):

$$I = \frac{HA}{\rho}\frac{\omega}{\sqrt{\{1+(L\omega/\rho)^2\}}}\sin(\omega t-\phi-\alpha)\sin\beta\sin D \qquad (6)$$

in which the symbols have the same meaning as before except that, referring to Fig. 2, N is now the projection of the normal to the inductor disk on the plane normal to the axis of inductor rotation, and ωt is the angle between that projection and the axis of the original pick-up coil A in Fig. 3.

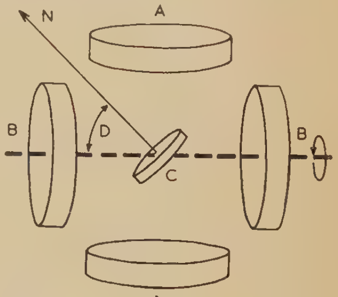


Fig. 3. Essential features of twin-coil TIM

A, second harmonic pick-up coils;
B, first harmonic pick-up coils;
C, tipped inductor.

The A coil signal will still be given by equation (4). However, L_m must first be replaced by $L_{mA\|}\sin D$, where $L_{mA\|}$ is what the mutual inductance would be if the axes of coil and inductor were parallel. (This relation also is subject to the remark after equation (3).) Equation (3) then gives

$$E_{coil\,A} = \frac{L_{mA\|}HA}{\rho}\frac{\omega^2}{\sqrt{\{1+(L\omega/\rho)^2\}}}\cos(2\omega t-\phi-\alpha)\sin\beta\sin^2 D \qquad (7)$$

So this output is the same as with an untipped disk, except for a $\sin^2 D$ loss in signal.

Because the disk is tipped the circulating currents in it will produce an oscillating component of H parallel to the inductor axle at the first harmonic of the inductor rotation frequency. This is detected by the B coils.

$$E_{coil\,B} = L_{mB\|}\cos D\,(dI/dt) \qquad (8)$$

where $L_{mB\|}\cos D$ is the mutual inductance between the inductor and coil B, so

$$E_{coil\,B} = \frac{L_{mB\|}HA}{\rho}\frac{\omega^2}{\sqrt{\{1+(L\omega/\rho)^2\}}}\cos(\omega t-\phi-\alpha)\sin\beta\sin D\cos D \qquad (9)$$

still at the first harmonic. Since the $\sin\beta$ term still appears, this output also has a toroidal sensitivity pattern.

By comparing the A output with the B output one can tell the sign of the field. Suppose this is done by comparison by measuring the angle $\omega(t_2 - t_1)$, by which the first positive peak of the second harmonic signal follows a positive peak of the first harmonic signal.

From equation (7) $\quad 2\omega t_2 - \phi - \alpha = 0$

From equation (9) $\quad \omega t_1 - \phi - \alpha = 0$

giving $\quad \phi = -\{\alpha + \omega(t_2 - t_1)\}$

Once the value of α has been measured at the operating value of revolutions per minute, one phase comparison will tell the sign of $H_\perp$. This can be done by connecting the A and B coils in series and looking at the resulting waveform while the instrument is held so that H is parallel to the axis of the A coils. Depending on the sign of H the output will be either as in Fig. 4(*a*) or 4(*b*). Actually these perfectly symmetric pictures will result only if TIM is held so that there is an angle $-\alpha$ between the axis of the A coils and H, but if this is neglected the somewhat skewed pictures which result are still quite recognizable.

From equation (9) the B coil signal is greatest when D is 45 deg., at which angle it is equal to the A coil signal if the A and B coils are identical.

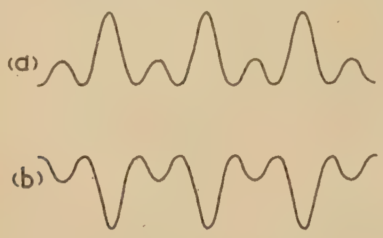


Fig. 4. Typical outputs from twin-coil TIM with A and B coils connected in series

An inductor made as shown in Fig. 3 would be dynamically unbalanced. The best answer to this problem so far has been to silver solder alternate sheets of copper and eureka together into one solid chunk and then turn a cylinder from this with the laminae at 45 deg. to the angle of rotation (see Fig. 5). Compared with copper, eureka is nearly an insulator, so electrically this rotor is a series of tipped disks. Because the two metals have nearly the same density, the dynamic balance is automatically good. The resulting smooth cylinder is a poor turbine so a polythene turbine wheel was constructed and pressed on with an interference of 6% of the diameter. The density of polythene is very low, so any likely inaccura will not upset the balance much.

With the twin-winding TIM it is possible to measu $\tan\alpha = \omega L/\rho$. With the inductor of Fig. 5 turning 42 000 rev/min it was about $\frac{1}{2}$. As expected, lower spe gave lower values of $\tan\alpha$. It is interesting to note tha

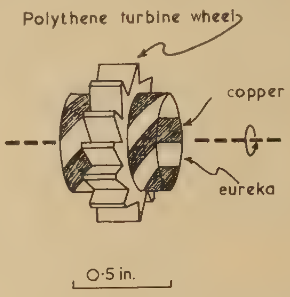


Fig. 5. Practical inductor for twin-coil TIM

the rotor were scaled up to 2 in. and were spun at the sa speed, which is perfectly possible, $\tan\alpha$ would be 8, givi $\alpha = 83$ deg., and the response would now vary approxima linearly with speed. In fact, the inductor resistance wou no longer be an important factor in controlling the circulati currents and, correspondingly, these would have a phase approaching 90 deg.

ACKNOWLEDGEMENTS

I wish to acknowledge the financial support of the Uni Kingdom Atomic Energy Authority.

Simple electrical analogue for the solution of linear simultaneou equations

By D. B. Dove, Ph.D., Wantage Radiation Laboratory, U.K.A.E.A., Wantage, Berks.

[*Paper first received* 23 *June, and in final form* 22 *July*, 1959]

A simple resistance analogue provides a rapid solution for simultaneous equations of the type $y_i = a_{ij}x_j$, where $a_{ij} = 0$, $i > j$.

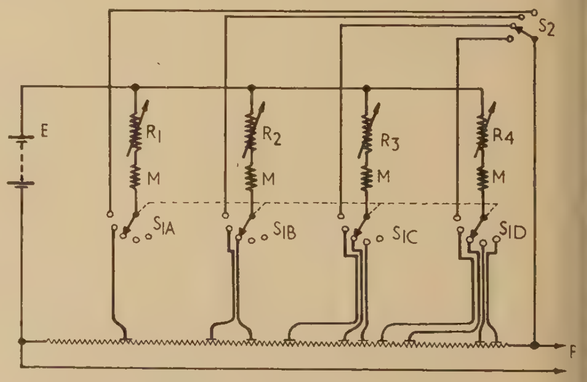
The analysis of γ-ray spectra by pulse-height analysis using a scintillation counter, or the analysis of a mass-spectrometer record, both require the solution of simultaneous equations of the form:

$$\begin{aligned} y_1 &= a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \dots + a_{1n}x_n \\ y_2 &= \qquad\quad\; a_{22}x_2 + a_{23}x_3 + \dots + a_{2n}x_n \\ &\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ y_n &= \qquad\qquad\qquad\qquad\qquad\quad a_{nn}x_n \end{aligned}$$

where the coefficients a_{ij} are instrumental constants, the y_i are experimental readings and the coefficients x_i are to be determined. It may be assumed without loss of generality that $a_{ij} \leqslant 1$.

THE ANALOGUE

Description of circuit. The circuit is shown in the figure for the case, $n = 4$. In the general case, currents I_1 to I_n pass through the parallel variable resistors R_1 to R_n respectively. Power is supplied by a 12 V high-capacity battery, left on continuous slow discharge for stability. A multi-way switch S_1 connects currents $I_1, I_2 \dots, I_n$ to tappings on a length of resistance wire, and the resulting potential drop along the wire is measured by a potentiometer. Switch position (n) connects I_n to a tapping corresponding to r and the remainder to open circuit. Position ($n - 1$) conne I_n to $r_{(n-1)n}$, $I_{(n-1)}$ to $r_{(n-1)(n-1)}$ and the remainder



Practical circuit, ($n = 4$)

R_1, R_2, R_3, R_4 = 1 MΩ variable resistors
M = 1 kΩ resistor
S_1 = Selector switch, n-pole, ($n + 1$)-way
S_2 = Read-out switch, 1-pole, n-way
P = μV potentiometer
E = high-capacity 12 V battery

en circuit; this is repeated down to position 1, where I_n I_1 are connected to tappings r_{1n} to r_{11} respectively. The istance tappings r_{ij} are set equal to Wa_{ij}, where W is the al wire resistance.

For accurate operation it is necessary that:

(i) The currents I_1 to I_n should not vary with setting of the selector switch.

ii) The currents should not interact. Current $I_p(p > m)$ causes a potential drop along the resistance wire, which tends to reduce currents $I_q(q \leqslant m)$.

simple application of Kirchhoff's laws shows that (i) and are satisfied provided $(n - 1)W$ is very much less than M, ere M is the minimum value of the current-adjusting istors R_i. In a practical arrangement, W is 1 Ω, M is)0 Ω, n is 20, and the maximum error resulting from (ii) 2%, this occurring in I_1 when I_2 to I_{20} are at maximum ting.

Operation. The variable y_n is represented by voltage V_n pre-set upon the potentiometer. With the selector switch at position (n), resistor R_n is adjusted until the potentiometer balances. Position $(n - 1)$ is now selected, the potentiometer is set to V_{n-1}, and R_{n-1} is adjusted until balance is reached. The procedure is repeated until R_n to R_1 have been set; the "read out" position is then selected and the currents I_1 to I_n measured by the resulting potentials v_1 to v_n across the resistance wire W. Provided the conditions (i) and (ii) are satisfied, then, because $v_i = WI_i$ and $a_{ij} = r_{ij}/W$, the following hold:

$$\begin{aligned} V_1 &= a_{11}v_1 + a_{12}v_2 + \ldots + a_{1n}v_n \\ V_2 &= \phantom{a_{11}v_1 + {}} a_{22}v_2 + \ldots + a_{2n}v_n \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ V_n &= \phantom{a_{11}v_1 + a_{12}v_2 + \ldots + {}} a_{nn}v_n \end{aligned}$$

If V_1 to V_n are set equal to y_1 to y_n respectively, the values of v_1 to v_n obtained provide the required solution x_1 to x_n.

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ngle pen, strip chart recorder for unattended long period operation

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[*Paper first received* 1 *April, and in final form* 9 *June,* 1959]

A battery operated recorder is described which is designed for operation for periods of 6 to 12 months without attention. It is suitable for recording such elements as water depth, rainfall, temperature, etc., and is provided with a solar time-check device which obviates the need for an expensive precision clock.

Recording is by a needle-pointed stylus which perforates the chart paper when depressed by a chopper bar. A relatively simple linkage is used to give a rectilinear traverse to the stylus.

INTRODUCTION

meet a demand for a relatively inexpensive recorder able of operating unattended for long periods at remote ations, the instrument described here was designed with following objectives in mind:

1) The recorder to operate unattended for 6 to 12 months with a chart speed of 3 in./d and for a proportionately shorter period at an optional higher chart speed of 12 in./d.
2) The instrument to be adaptable to the recording of water level, rainfall, temperature, etc., when fitted with appropriate sensing elements.
3) A rectilinear traverse of the recording stylus with a trouble-free marking system.
4) The inclusion of a time checking device.

DETAIL DESIGN

Chart drive. The recorder mechanism assembly is shown Fig. 1. A 115 ft length of chart paper, of width 4 in., ceeds from the spool *A* (Fig. 1), under the time check ne *B* (see below), over the driving sprockets *C* and is en up on the spool *D* which is driven by a spring belt. sprocket axle is ratchet actuated, as shown in the inset ail, power being provided by the solenoid *E*. This is iodically energized by the clock and switch unit *F*; in rating it depresses the chopper bar *G*, causing a needle-nted stylus at the tip of the pen arm *H* to perforate the rt. The return springs *J* then lift the chopper bar and the er is advanced by the ratchet drive. Paper speed is mally 3 in./d but reversing the gear train *K* gives 12 in./d.

lock unit. The clock is a standard "Kienzle" solenoid ind, spring clock powered by a 1·5 V dry cell. The hour dle carries a light 120-tooth wheel, the teeth of which actuate a "Micro" sub-minature, snap action change-over switch. On closure of the switch, a 135 V dry battery charges a 100 μF electrolytic capacitor through a 33 kΩ, 1 W resistor: on opening, the change-over contact discharges the capacitor through the solenoid. A silicon diode (OA 202) is connected across the solenoid to suppress the sparking which is otherwise found to occur at the switch contacts.

Time check. As the clock cannot be expected to keep exact time over a period of months, a time check device utilizing the noon sun is provided. This consists of a $2\frac{1}{2}$ in. diameter biconvex lens of 2 in. focal length so mounted as to focus the sun's image on the chart at noon. A metal plate with a $\frac{1}{16}$ in. slit at right angles to the time axis of the chart, and close above it, protects the chart from being burnt except for a short time while the sun transits the meridian at local apparent noon. To obtain a sharp enough focus for burning at all seasons the chart is passed through guides to give it the necessary concave cross-section when passing behind the slit. For any given latitude the lens is best set with its axis at the elevation of the noon sun at the equinoxes, i.e. at an elevation angle equal to the colatitude. In the present design the lens is adjustable to suit any latitude between 0 and 40°.

To obtain accurate time marking by this system the recorder must be correctly oriented and allowance made for the difference between local apparent noon and local mean noon. This difference, called "the equation of time", is often negligible but at some times of year is as much as fifteen minutes.

Pen mechanism. To secure a rectilinear traverse of the pen point to a sufficient degree of accuracy for practical purposes, the comparatively simple linkage shown in Fig. 2 was adopted. This is a modification of that described by Zschokke* but avoids the use of a sliding guide which could be troublesome in the present application.

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* ZSCHOKKE, M. *Rev. Sci. Instrum.*, **19**, p. 552 (1948).

The pen mechanism consists of three levers (Fig. 2) having four pivot points; pen arm *A* has a floating pivot (1) to which is connected lever *B* mounted on a stationary pivot (2). The lower end of the pen arm is pivoted (3) on lever *C* which in turn is mounted on stationary pivot (4). The active element (pressure capsule or bimetal, etc.) is connected to lever *C* in an adjustable manner using the ranging screw *D*.

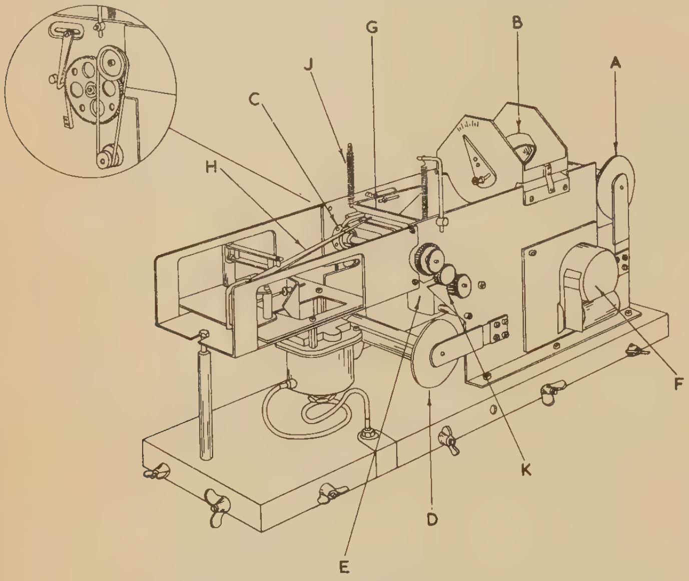

Fig. 1. Recorder mechanism assembly

For this mechanism it can be shown (with the notation of Fig. 3) that Δ the departure of the pen from a rectilinear traverse, is given by

$$\Delta = (a + b) \cos (\theta - \alpha) - c \cos \theta - (a + b - c) \quad (1)$$

where $\cos (\theta - \alpha) = \dfrac{BC + A(A^2 + B^2 - C^2)^{1/2}}{A^2 + B^2}$

and $A = (e - c \sin \theta)$

$B = b - c(1 - \cos \theta)$

$C = c/b\{(b - c) \cos \theta + c - e \sin \theta\} + (b - c)$

The dimensions chosen in the present recorder were

$$a = 6,\ b = 3,\ c = 1{\cdot}15 \text{ and } e = 3{\cdot}37 \text{ in.}$$

which give the following values of Δ

θ degrees	0	15	30	45
Δ inches	0	$-0{\cdot}004$	$-0{\cdot}010$	$+0{\cdot}005$

As to linearity of the pen deflexion in relation to the input, it can be shown that if *e*, the length of lever *B*, can be made large enough for the lateral movement of pivot (1) to be neglected in comparison with its longitudinal motion, then

$$D' = \frac{ac}{bd} \times D$$

so with an input displacement *D* applied in such a manner that $\sin \theta \propto D$ there is no loss of linearity in the recorder.

Mounting. Appropriately oriented, the instrument is mounted on a 2 in. diameter steel tubular support. The cover, with Perspex window for the lens, is arranged to give adequate ventilation to the instrument but to exclude insects. A perch for birds is so disposed as to reduce the chance of the window being fouled.

PERFORMANCE

A prototype instrument has been tested near the laborato for a period of eight months without change of batteries. is an important advantage of the capacitor-solenoid co bination that only a very small current is taken from t battery. Rising internal resistance is therefore unimporta and the battery's life is nearly equal to the shelf life.

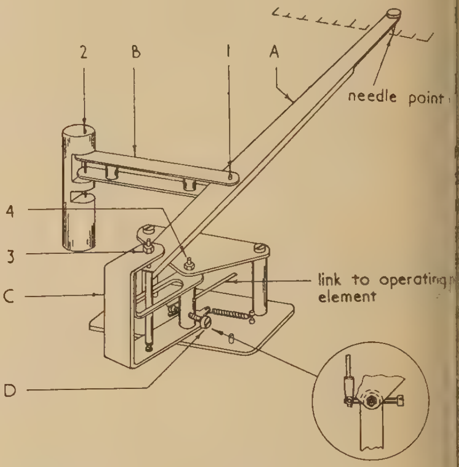

Fig. 2. Pen mechanism assembly

A blue bank paper with a fibrous surface is found m satisfactory for the chart rolls as this gives a satisfact time-mark burn. The usual highly glazed white papers f ink recording are unsuitable. A light behind the cha facilitates analysis of the record perforations.

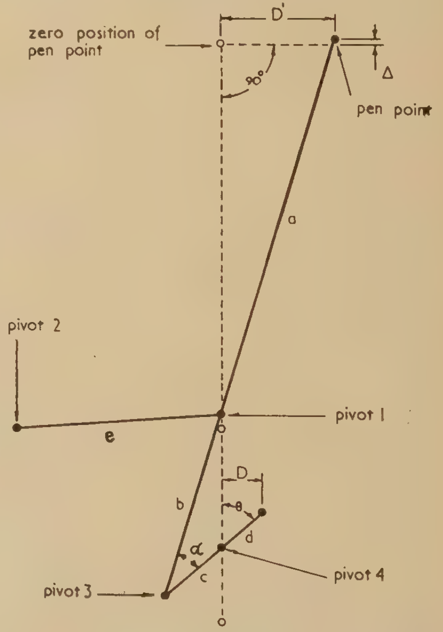

Fig. 3. Diagram of pen arm mechanism

Long term field trials are now in progress and the instr ment has operated successfully for two months; water lev in a stream is being recorded in terms of pressure head abo a flexible membrane sensing element.

ACKNOWLEDGEMENTS

e author is indebted to Mr. T. G. Chapman of the ion of Land Research and Regional Survey, C.S.I.R.O., erra, for his constructive comments throughout the development of this instrument. Acknowledgements are also due to Mr. F. J. Maher and Miss Y. M. Mullins for their assistance in developing the electrical system and to Mr. B. Turner who constructed the prototype instrument.

Laboratory and workshop notes

Precision pressure gauge for the range 0 to 30 mm of mercury

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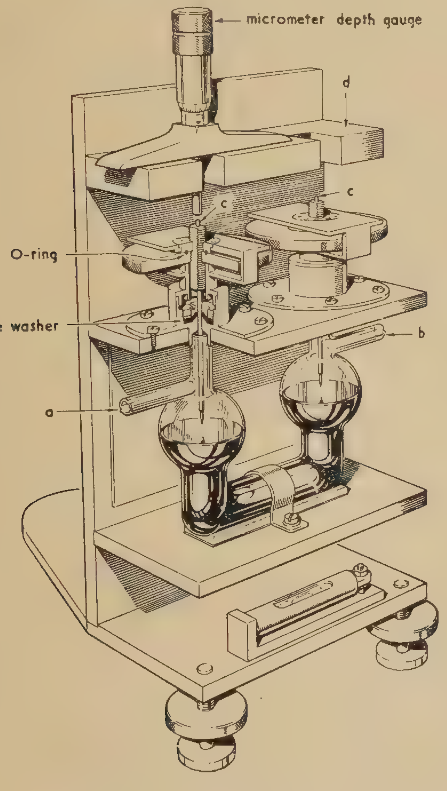
ote first received 26 *February, and in final form* 18 *June,* 1959]

pressures of the order of 1 mm of mercury lie just below proper working range of normal U-tubes, Bourdon ges, etc., whilst on the other hand such pressures are too to allow accurate measurements with the conventional vacuum gauges. It is the purpose of this note to describe mple absolute gauge, covering this intermediate range, ch permits pressure measurements in the range from 30 mm of mercury with a high degree of accuracy.

he instrument operates on the U-tube principle, but in er to eliminate errors due to friction and capillarity the os of the manometer are in the shape of glass bulbs of roximately 40 mm diameter, half-filled with mercury and nected by a 15 mm diameter tube (see the figure).



Precision pressure guage

he unknown pressure difference, applied to the side tubes nd *b*, is measured in terms of the difference in mercury l in the two bulbs. The latter is determined by means of movable rods carrying fine points, which pass through vacuum-tight seals into the space above the mercury. A simple screw mechanism allows the points to be raised or lowered and, with the help of a reading lens or low-power microscope, the mercury level is found by observing contact between the fine point and its mirror image in the mercury surface.

The first step in making a pressure measurement is to obtain a zero reading by connecting both bulbs to the same pressure, bringing the points into contact with the surface and measuring the distance of the top *c* of each rod from a reference plane *d* by means of a micrometer. This process is repeated with the pressure difference applied, the latter being given directly by the change in micrometer readings.

Obviously the gauge may be used either for absolute pressure measurements in the millimetre range, or for the determination of small pressure differences at higher pressures, for instance at atmospheric pressure. In the former case the zero reading is taken with both bulbs at a pressure smaller than the readable accuracy of the instrument, below 1 μ say, whilst in the latter case the zero is read at the pressure at which the difference is to be measured.

The obtainable accuracy is naturally limited by the type of micrometer used. The simple and inexpensive depth gauge arrangement shown in the figure will permit an accuracy of about $\pm 15\ \mu$ of mercury, but a higher accuracy can be achieved by fitting a good quality micrometer head permanently over each measuring rod.

The instrument then allows pressure measurements to $\pm 2\ \mu$ over a range from 0 to 10 mm of mercury. Beyond this range incomplete compensation of surface tension effects, due to the spherical shape of the bulbs, progressively reduces the accuracy, but at 30 mm of mercury measurements can still be made to 0·1% or better. If desired, a more extended range of high precision can be achieved by using cylindrical rather than spherical glass containers, in which case, however, a greater mercury charge is required. Apart from the commercially available micrometer heads, the construction of the gauge requires no work of great precision.

Small mechanical inaccuracies, such as backlash in the screw mechanism, do not actually affect the measurements themselves, but in order to facilitate adjustment backlash is taken up by a slightly compressed elastomer O-ring recessed into the driving nut.

For high accuracy the level of the gauge must, of course, remain constant throughout the taking of a measurement, and it is also desirable to use fairly sharp points, having a tip radius of the order of 0·01 mm. Such points, which are mechanically quite robust, may readily be made by electrolytic etching of a tungsten rod (approximately 1 mm diameter) in a 20% normal solution of potassium hydroxide, using 10 V a.c. The gauge is mounted on a rigid mild steel frame, and the glass and metal parts are sealed vacuum tight by means of glyptal resin.

The author wishes to thank Dr. W. Schwietzke for his interest and encouragement throughout the work. Thanks are also due to the Chief Scientist, Department of Supply, Australia, for permission to publish this note.

Linear saw-tooth time base

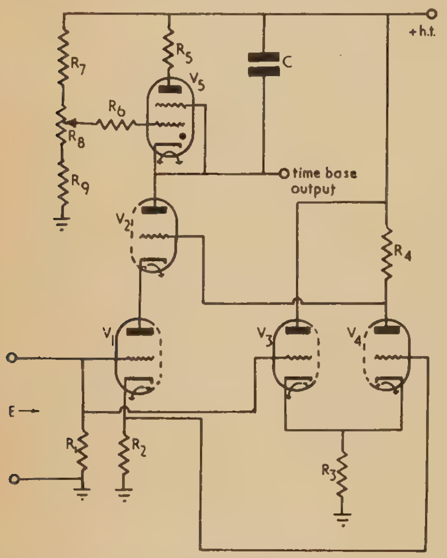
By J. S. Mainstone, B.Sc., Ph.D., Department of Physics, University of Adelaide, S. Australia

[*Note first received* 16 *March, and in final form* 8 *July,* 1959]

For the production of a linear saw-tooth time base the voltage v across the time base capacitor must change linearly with time, i.e. dv/dt must be constant for the duration of the sweep. Thus the current flowing into the capacitor during the charging process must be kept constant.

A pentode is often used as a constant current generator but since the degree of linearity which can be achieved depends on the pentode characteristic, perfect linearity cannot be obtained in this way. Nevertheless such a circuit is adequate for many practical applications.

Puckle(1) lists several methods of linearization of the trace by compensation for the curvature of the charging characteristic. An alternative approach, using a constant current generator of the type described by Clarke(2) is given in the figure. The circuit provides a very high degree of linearity even at very low sweep frequencies, and has been used successfully in a display unit requiring an extremely linear time base for the measurement of meteor velocities. The sweep frequency for which the circuit is primarily designed is of the order of 5 to 10 c/s.



$R_1 = 1$ MΩ
$R_2 = 39$ kΩ
$R_3 = 47$ kΩ
R_4, $R_8 = 470$ kΩ
$R_5 = 60$ Ω
$R_6 = 56$ kΩ
$R_7 = 100$ kΩ
$R_9 = 220$ kΩ

$C = 2$ μF

$V_1 + V_2 =$ 12AU7
$V_3 + V_4 =$ 12AX7
$V_5 =$ PL5727

The constant current generator consists of a 12AU7 regulator ($V_1 + V_2$) and a 12AX7 difference amplifier ($V_3 + V_4$). This arrangement is suitable for charging currents greater than about 1 mA. For currents less than 1 mA a 12AX7 is more suitable as the regulator tube.

If i is the current flowing into the capacitor C during the forward stroke of the time base, the voltage developed across the cathode resistor of V_1 is iR_2. The difference between the value of iR_2 and the potential E applied to the grid of V_1 is amplified by the difference amplifier $V_3 + V_4$ and applied to the correcting tube V_2. In this way the current i is kept constant to within very close limits.

Since the current i is determined by the applied potential E, variation of E by means of a potentiometer provides the velocity control for the time base.

The discharge path for the capacitor is through a PL5727 thyratron. The sweep amplitude is controlled in the conventional way by varying the striking potential of th thyratron with the potentiometer R_8. With a h.t. voltag of 380 V, a maximum time base amplitude of 250 V obtainable with the circuit shown.

When the applied potential $E = 100$ V, i.e. the circuit arranged to give a charging current of 2·5 mA, the generato behaves as a source impedance of the order of 40 MΩ Under rather similar conditions, Clarke has demonstrate experimentally that the current can be expected to remai constant to within approximately 0·1%, regardless of th load impedance. In the case of the time base, the capacito as it is being charged behaves as a continuously changin load impedance. The linearity of the saw-tooth generate by the circuit is in accordance with that expected from th current regulation measured by Clarke and is a considerab improvement on that obtained by other methods.

REFERENCES

(1) Puckle, O. S. *Time Bases*, 2nd ed. (New York: Jo Wiley and Sons, Inc., 1951).
(2) Clarke, L. N. *Electronic Engng*, **28**, p. 223 (1956).

Thermoelectric e.m.f. of tin-cadmium alloys

By H. Charnock, M.Sc., A.Inst.P., and S. A. Yeo, B.Sc., National Institute of Oceanography, Wormley Godalming, Surrey

[*Note first received* 2 *April, and in final form* 17 *July,* 1959]

The design of galvanometers and d.c. amplifiers has improve to the stage when small voltages, of the order of microvolt can be accurately measured and recorded. In many cases th accuracy is limited by unwanted thermoelectric e.m.f.s the sensing elements and in the early stages of the amplifie or recorders. When thermocouples or resistance therm meters are used for meteorological measurements, suc spurious e.m.f.s are especially troublesome because th instruments are exposed to varying solar radiation and wi

It is often useful in reducing these unwanted e.m.f.s, have a solder which has little or no thermoelectric e.m.f. copper. Liston *et al.** recommend a 75 Cd/25 Sn allo as a suitable solder; in this note measurements are given the thermoelectric e.m.f. of this and other Cd/Sn alloys.

The initial measurements were made on alloys 20 Cd/80 Sn, 32 Cd/68 Sn, 65 Cd/35 Sn, 70 Cd/30 Sn an 75 Cd/25 Sn. These samples were supplied in the form blowpipe strips (by Messrs. Fry and Co.) and their con position checked chemically. At the suggestion of a refere a second series of measurements was made on C 90 Cd/10 Sn and Sn using samples again supplied by Messr Fry but originally in the form of small ingots. These we converted to strips by melting them and sucking the molte material into glass tubing.

The thermoelectric e.m.f. of all the samples was measure relative to copper wire (Lewmex, 24 s.w.g.). One junctio was kept in melting ice and the other in a stirred water bat the temperature of which was measured to 0·1° C using standardized thermometer. The resulting e.m.f. w measured to rather better than a microvolt by using a goo quality potentiometer.

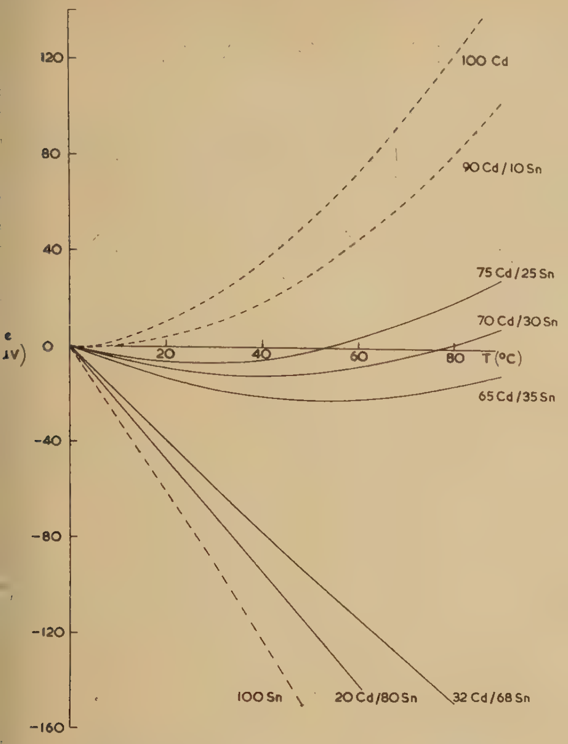
The results are shown in Fig. 1. They can be represente within the error of observation, by the usual parabolic formu

$$e = aT + bT^2,$$

---

* Liston, M. D., Quinn, C. E., Sargeant, W. E., and Scot G. G., *Rev. Sci. Instrum.*, **17**, p. 194 (1946).

e e is the e.m.f. in microvolts and T the temperature in ees C. The values of the constants a and b for each alloy, her with other data, appear in the table.



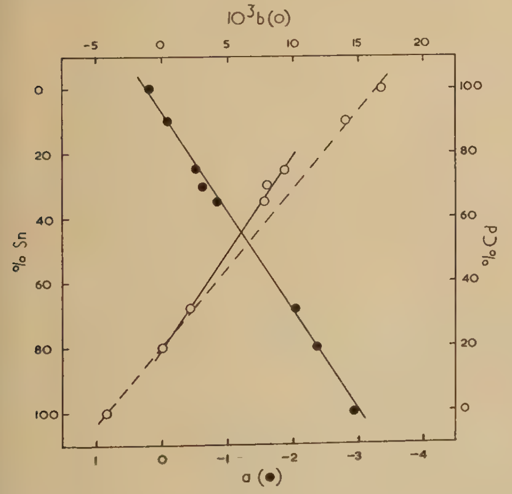
g. 1. Thermoelectric e.m.f. of Cd, Sn and Cd/Sn alloys, relative to Cu, in range 0–80° C

e full lines refer to the first series of samples tested (see t). The voltage is reckoned positive if current would flow from the test metal to the copper at the cold junction.

Values of constants

alloy Cd/Sn	*a* (μV/°C)	*b* [μV/(°C)²]	*neutral pt.* (°C)
100	0·20	$16{\cdot}8 \times 10^{-3}$	−6·0
90/10	−0·10	$14{\cdot}1 \times 10^{-3}$	3·5
75/25	−0·51	$9{\cdot}4 \times 10^{-3}$	27
70/30	−0·62	$8{\cdot}1 \times 10^{-3}$	38
65/35	−0·83	$7{\cdot}9 \times 10^{-3}$	53
32/68	−2·04	$2{\cdot}2 \times 10^{-3}$	460
20/80	−2·37	$0{\cdot}06 \times 10^{-3}$	20 000
100	−2·93	$-4{\cdot}2 \times 10^{-3}$	−350

can be seen from Fig. 2 that both a and b vary approxi-ely linearly with composition. The values of a for both of samples are consistent; those for b show small, but matic differences. This may be caused by slight differ-s in the purity and manner of preparation of the samples. e alloys with high cadmium content melt about 200° C all can be used as solders with only a little more care than the usual Pb/Sn alloy. The 75 Cd/25 Sn is most convenient in use. A typical lead/tin solder (60P6/40Sn) was found to have the same thermoelectric e.m.f. as pure tin.



g. 2. Values of a and b, constants in $e = aT + bT^2$, relation to composition of Cd, Sn and Cd/Sn alloys e full lines refer to the first series of samples tested (see text).

Chemical cleaning of oxidized nickel-iron-cobalt alloys for glass-to-metal seals

By N. Rain, S.E.R.L. Baldock, Herts.

[*Note received* 23 *July*, 1959]

During the glass-to-metal sealing process, alloys of the nickel-iron-cobalt type (Nilo K, Kovar) become heavily oxidized and it is necessary to remove this oxide before further processing, such as electroplating, can take place. The removal of this oxide without appreciable attack on the underlying metal is not easy. Several methods* have been put forward but the following process has been found to be the most reliable and effective.

The glass-to-metal seal, freed of any grease, is immersed in Solution 1 until, on inspection, the metal is seen to be free of oxide. The time can vary from ten to sixty minutes depending on the thickness of oxide. A rinse in chromic-acid solution will remove any smut remaining. Loss measurements on unoxidized Nilo K in Solution 1 at 75° C represent a loss from the surface of 0·0004 in. of the alloy per hour.

The addition of nitric acid to Solution 1 gives an etchant for oxide-free Nilo K which produces a bright finish. This etchant (Solution 2) has found use as a cleaning pickle for nickel-iron-cobalt alloy prior to glass sealing, and an etchant for nickel components where an etched surface is required. The optimum temperature is 60° C and the reaction is fairly vigorous. At this temperature 0·001 in. of alloy is lost from the surface per minute. A ten- to thirty-second dip is usually adequate to produce a clean bright finish. Again the smut can be removed by a chromic-acid dip.

Solution 1	Ferric ammonium sulphate	50 g
	Sulphuric acid 1·84	125 ml
	Hydrochloric acid 1·16	150 ml
	Water	to make 1 l.
	Temperature	60°–80° C
	Chromic Acid	
	Chromium trioxide	100 g
	Sulphuric acid 1·84	30 ml
	Water	to make 1 l.
Solution 2	Ferric ammonium Sulphate	50 g
	Sulphuric acid 1·84	125 ml
	Hydrochloric acid 1·16	150 ml
	Nitric acid 1·42	150 ml
	Water	to make 1 l.

---

* Hot hydrochloric acid and zinc. (Source unknown.)
Nitric, hydrochloric, acetic acids and pyridine (5 : 5 : 2 : 2) 50° — 60° C. (Source unknown.)
Ammonium sulphate in sulphuric acid. (Brit. Pat. No. 795980.)

NOTES AND NEWS

Notes and comments

BINDING ORDERS

Orders and enquiries about the binding of back-numbers of this *Journal* should be sent direct to Messrs. E. A. Weeks and Son, 168 Gower Street, London, N.W.1. (EUSton 4674), and *not* to the Institute. The price for binding has been reduced and will in future be 22*s*. post free (standard case). Separate cases are also available at a reduced rate of 13*s*. 6*d*.

Planetary and space science

The first issue of a new bi-monthly periodical entitled *Planetary and space science* has recently been received. Its aim is to serve as a medium for the publication of original work on the upper regions of the earth's atmosphere, the planets, interplanetary space and all related problems. The Editor-in-chief is Mr. M. Greenberg and the first issue, published in January, contained contributions on: Far ultra-violet radiation in the night sky; Spectroscopic study of the afterglows of N_2 and $(N_2 + O_2)$ in the vacuum region; Energy sources of the upper atmosphere; An interim atmosphere derived from rocket and satellite data; Micrometeorite measurements from 1958 Alpha and Gamma satellites; The airglow of Venus; Re-entry of the Sputnik I rocket; A short duration afterglow of nitrogen; Survey of afterglows; Decay of spin in Sputnik I; Absorption refraction and scintillation measurements at 4700 Mc/s with a travelling-wave tube radiometer; Hydrogen emission and two types of auroral spectra; On hydrogen emission in the night glow; The distribution of helium-3 in the Grant meteorite and a determination of the original mass; IGY rockets and satellites a report on the Moscow meetings, August 1958.

The periodical is published by the Pergamon Press Ltd., 4 and 5 Fitzroy Square, London, W.1. The subscription price, including postage, is £7 per volume (U.S.A. $20.00). For subscribers certifying that the periodical is for their own personal use the price is £3 10*s*. per annum (U.S.A. $10.00).

Reactor technology

We have received a copy of the first issue of a new quarterly entitled *Reactor Technology*, being Part B of the *Journal of Nuclear Energy*, under the general Editorship of Dr. J. V. Dunworth of the United Kingdom Atomic Energy Authority. This new quarterly is stated to have been "founded to provide an international medium for publication of papers on technological subjects drawn from all scientific disciplines which contribute to the development of nuclear energy for peaceful purposes". In the issue before us there are six British papers and one which is a translation from the Russian; in addition there are nine letters to the Editors. All the translations are from 1937 issues of the Russian periodical, *Atomn* *Energiya*. The annual subscription price is £7 per volu including postage, and the publishers are Pergamon P Ltd., of London, New York, Paris and Los Angeles.

Polymer

Polymer has been founded to provide an internatio medium for the publication of original papers on the chemis physics and application of polymer research, and on ot disciplines which contribute to the development of pol science. The research effort now devoted to this fi together with the number of papers written on the subj is now considered large enough to justify the publication this new and specialized journal. A feature of the jour will be the publication of short communications dealing w work which merits publicity before a full paper can be p pared and published. These communications, like the pa will be refereed and edited.

Polymer will appear quarterly, commencing January 19 and will contain about 500 pages per volume. The p will be £5 per volume, and subscriptions should be pla with Butterworths Scientific Publications, 4 & 5 Bell Ya London, W.C.2.

British Journal of Applied Physics

Contents of the November issue

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Papers

Some aspects of the design of large permanent magnets. By J. E. Cousins W. F. Nash.

Some aspects of the theology of milk gel. By C. S. Landau.

Correction for size of cross-section of the secondary windings of mutual induct standards of the Campbell type. By P. Vigoureux.

NEW BOOKS SECTION Reviews (List of books received)

ORIGINAL CONTRIBUTIONS (*continued*)

Cathode work function, sparking potentials and secondary ionization coeffici for oxide-coated cathodes in hydrogen. By D. E. Davies and B. J. Hopk

Influence of the cathode work function on the sparking potential in hydro By D. E. Davies and R. K. Fitch.

Efficiency of characteristics Kα X-ray production in copper between 9 and 15 By N. A. Dyson.

Electrical conductivity of vitrain during carbonization. By M. I. Pope S. J. Gregg.

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ORIGINAL CONTRIBUTIONS

Nuclear resonance absorption circuit

By F. N. H. Robinson,* M.A., D.Phil., Clarendon Laboratory, Oxford

[*Paper first received* 13 *April, and in final form* 14 *May*, 1959]

The new circuit described in Part 1 has the sensitivity and flexibility of conventional circuits using a separate oscillator, combined with the convenience and freedom from microphonics of marginal oscillator circuits. In particular, it permits the use of very low levels of oscillation.

Because the factors governing the sensitivity of conventional circuits are not widely known, this first paper is largely devoted to their delineation. Only the principles and theory of the new circuit are given in Part 1. Practical design details are relegated to the second paper.

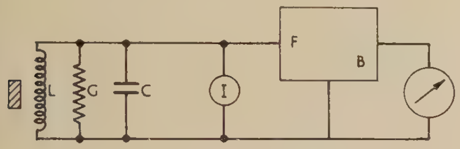
Part 1. Sensitivity considerations

ear resonance absorption in a specimen surrounded by l forming part of a tuned circuit changes the quality r Q by

$$\delta(1/Q) = 4\pi\eta\chi'' \qquad (1)$$

e η is a filling factor and χ'' is the imaginary part of the ar susceptibility. The excellence of any circuit for ting nuclear resonance (n.r.) absorption can therefore pecified by giving that change $\delta(1/Q)$ which yields a l equal to noise.

e simplest n.r. circuit (Rollin(1)) is shown in Fig. 1, in h a constant current generator I drives the resonant it (L, C with loss G) at its natural frequency. N.R. rption changes the shunt impedance of the circuit and the voltage across it. This change is detected by a ver of bandwidth B and noise figure F.



g. 1. Simple nuclear resonance circuit using a separate oscillator

change $\delta(1/Q)$ results in a fractional change $Q\delta(1/Q)$ in shunt impedance and so, if the r.m.s. voltage in the nce of signal is V_1, it is changed by:

$$\delta V_1 = -V_1 Q\delta(1/Q) \qquad (2)$$

effective r.m.s. noise voltage across the coil is

$$V_n = (4kTFB/G)^{1/2} \doteq (4kTFBQ/\omega c)^{1/2} \qquad (3)$$

s unity signal-to-noise ratio is achieved when

$$\delta(1/Q) = \frac{1}{V_1}\left(\frac{4kTFB}{Q\omega c}\right)^{1/2} \qquad (4)$$

tical results are obtained for bridge circuits, the only ose of which is to give the experimenter freedom to mize the receiver noise figure by working with the num input.

e voltage V_1 cannot be indefinitely increased because of ear saturation. If the maximum permissible r.f. magnetic field is H_1 then energy considerations yield the following relation

$$V_1^2 C \leqslant H_1^2 U/4\pi\eta \qquad (5)$$

where U is the specimen volume.

At the optimum level a value of χ'' satisfying

$$H_1\chi'' \doteq \left(\frac{kTFB}{\pi\omega Q U\eta}\right)^{1/2} \qquad (6)$$

gives a signal equal to noise. Both H_1 and χ'' are beyond the experimenter's control. To optimize the signal-to-noise ratio one can only increase Q, U, η and decrease F and B. Of these only Q, F, B pertain to the circuit. Factor Q is limited partly by the experimental arrangement and partly by the physical properties of materials. Bandwidth B is limited by the stability of the equipment and by the time available for measurement. Thus, all that the circuit designer can do is to attempt to ensure that F does not appreciably exceed unity.

It is interesting to note that C does not enter into equation (6) directly. The L/C ratio of the circuit is immaterial, except in so far as it affects Q and determines V_1 through equation (3).

This simple arrangement is, in principle, capable of the highest possible sensitivity; however, it suffers from certain well-known disadvantages. In particular, it is inconvenient in that it requires the accurate tracking of the oscillator I and the n.r. circuit; and it is prone to microphonic noise, due to small charges in the capacity of the coil and its leads.

A small change ΔC in capacity produces a spurious signal equivalent to a change $\Delta(1/Q)$ given by

$$\Delta(1/Q) = Q(\Delta C/C)^2 \qquad (7a)$$

if the circuit is perfectly tuned; and a spurious signal

$$\Delta(1/Q) = Q(\Delta C_0/C)(\Delta C/C) \qquad (7b)$$

if it is mistuned by an amount ΔC_0. In practice, it is difficult to tune a circuit to an accuracy greater than α/Q where α is of the order of 0·2 (this implies maximizing the response of the circuit to within 4%), so that

$$\Delta(1/Q) \simeq 0{\cdot}2(\Delta C/C) \qquad (7c)$$

In bridge circuits microphonics are even more serious.

An alternative arrangement without these disadvantages is the marginal oscillator circuit described by Pound and Knight.(2) It is illustrated in Fig. 2. Oscillations are maintained by a non-linear negative conductance $-G'$ provided by a valve feedback circuit. The sources of noise have been depicted as a current generator I_n, in which is included the Johnson noise of the circuit, so that I_n has the r.m.s. value

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* English Electric Research Fellow.

$$I_n = (4kTF_0GB)^{1/2} \tag{8}$$

where F_0 is the noise figure of the feedback circuit.

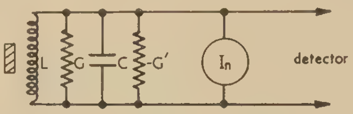

Fig. 2. Basic marginal oscillator circuit

Let the dependence of G' on level be of the form

$$G' = G_0 - G_1V_1 - G_2V_1^2 \ldots \tag{9}$$

then the level of oscillation V_1 is determined by equating the average power delivered by G' to the power dissipated in G.

$$\frac{1}{2\pi}\int_0^{2\pi}(G_0V_1^2\sin^2 x - G_1V_1^3\sin^3 x - G_2V_1^4\sin^4 x)dx = \frac{1}{2\pi}\int_0^{2\pi} GV_1^2\sin^2 x dx$$

Therefore

$$V_1 = \left(4/3\,\frac{G_0 - G}{G_2}\right)^{1/2} \tag{10}$$

Since $G = \omega c/Q$, one has for the signal voltage

$$\delta V_1 = -\tfrac{1}{2}V_1\frac{\omega c}{G_0 - G}\,\delta(1/Q) \tag{11}$$

Provided that the bandwidth B is small compared with ω/Q, which is usually the case, it can be shown(3) that, except for a vanishingly small locking region near ω, the circuit behaves towards noise as an admittance $|G_0 - G|$, so that the noise voltage is

$$V_n = I_n/(G_0 - G) \tag{12}$$

and unity signal-to-noise ratio requires a change

$$\delta(1/Q) = \frac{2}{V_1}\frac{I_n}{\omega c} = \frac{2}{V_1}\left(\frac{4kTF_0B}{Q\omega c}\right)^{1/2} \tag{13}$$

This is just twice the detectable change for the circuit of Fig. 1 if $F = F_0$. The factor 2 obviously occurs because in this case the voltage depends on the root of the circuit impedance.

APPLICATION TO CONVENTIONAL CIRCUITS

Now consider the noise figure of two types of marginal oscillator circuit, true negative resistance oscillators and feedback circuits. A typical negative resistance oscillator is the transitron circuit of Knoebel and Hahn(4) (Fig. 3). The sources of noise in this case are Johnson noise in G and shot noise in I_2. Since this is a small fraction of the total cathode current, partition ensures that it displays full s noise.

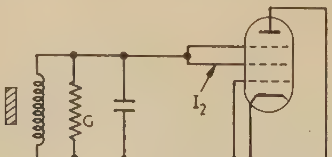

Fig. 3. Skeleton transitron oscillator

$$I_n^2 = 4kTGB + 2eI_2B$$

Inserting numerical values for e and k and putting $T = 29$ one obtains

$$I_n^2 = 4kTGB(1 + 20I_2/G)$$

or

$$F_0 = 1 + 20I_2/G$$

Since in a typical case $I_2 = 2 \times 10^{-3}$ A and $G = 2 \times 1$ mho, one has a value of $F_0 = 201$ and this circuit is insensitive.

In Fig. 4, the structure of a feedback oscillator usin valve of mutual conductance g_m and noise resistance R shown. The oscillation condition is

$$\alpha\beta g_m = G$$

and the noise current generator, in addition to Johnson no contains shot noise from the anode current given by

$$I_s^2 = \beta^2 4kTR_nBg_m^2$$

This leads to a noise figure

$$F_0 = 1 + R_nG/\alpha^2$$

where α is the fraction of the circuit voltage actually app to the grid. Only in the inductively-coupled tuned oscillator is this unity. For the Colpitts and Hartley circ the value of α is from $\frac{1}{4}$ to $\frac{1}{2}$, in the Pound, Knight, Wat circuit(5) $\alpha \sim \frac{2}{3}$, while in the Clapp circuit $\alpha \sim 0{\cdot}2$.

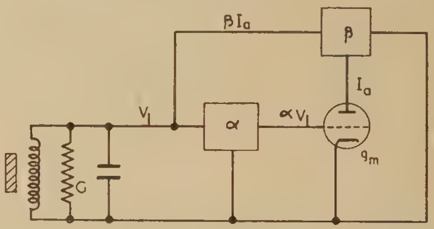

Fig. 4. Basic feedback oscillator

Equation (13) shows that even if F_0 is unity, marg oscillators are only half as sensitive as separate oscilla systems using the same method of detection. In fact, F unlikely to be unity except in the most favourable cases. high values of V_1 either one must use a long grid base va with a low g_m and high R_n, or reduce α, or the valve is into grid current, thus introducing additional noise. At levels of V_1 the valve must be used near cut-off, thus decr ing g_m and increasing R_n. Only when V_1 lies between and 500 mV is it possible to make $F_0 \simeq 1$.

LOW LEVEL OPERATIONS

Suppose that the feedback, or equivalently G, can adjusted to a fractional accuracy ϵ so that

$$G_0 = G(1 + \epsilon)$$

Then the level is given by

$$V_1^2 = (4\epsilon/3)(G_0/G_2)$$

The negative conductance is proportional to the valve mu conductance and so:

$$\epsilon = -(3/8g_m)V_1^2(d^2g_m/dV^2)$$

he triode is interpreted in terms of the usual equivalent de, the anode voltage of which is $(V_g + V_a/\mu)$ one has

$$I_a = K(V_g + V_a/\mu)^{3/2}$$
$$g_m = 3/2K(V_g + V_a/\mu)^{1/2}$$
$$d^2g_m/dV^2 = -3/8K(V_g + V_a/\mu)^{-3/2}$$

l so

$$\epsilon = (\tfrac{1}{24})(V_1 g_m/I_a)^2 \qquad (16)$$

r tubes such as the types 6AK5 and EF91, $g_m/I_a \sim \frac{1}{2}$ at normal working point increasing to about 1 at a tenth normal current, while for high gain tubes such as the e E180F the corresponding figures are 1·2 and 2·4. If takes the latter figure, a level of 10 mV requires an uracy ϵ of better than twenty-four parts per million. In st practical cases it is the difficulty of maintaining the bility of the circuit components to this accuracy which a lower limit to the level, although it should be noted t a more fundamental limit at still lower levels is set by locking phenomenon mentioned earlier. The region over ich the oscillator locks to noise increases as a high negative wer of V_1. These considerations apply only to circuits hout automatic level control (a.l.c.). Using a.l.c. it is ssible to compensate the effect of component instability. ıme[(6)] has achieved levels of 40 μV using high g_m triodes a modified Pound–Watkins circuit with a refined a.l.c. tem.

n typical circuits the tube providing regeneration is run a current approaching one-tenth of its normal rating. As esult g_m is reduced and R_n increased five-fold. If one takes an example a circuit with $G = 1/5000$ mho using a triode-nnected type 6AK5 tube, $R_n = 5 \times 500\,\Omega$ and, with $= \frac{1}{2}$, one has $F_0 = 1 + 2$. Assuming a perfect detector circuit is $2\sqrt{3} \sim 3{\cdot}5$ times less sensitive than ideal.

COMPARISON OF CIRCUITS

Marginal oscillators are, nevertheless, widely used because the convenience of having only one frequency to control d their freedom from microphonics. Since the frequency usts itself to changes in C, a change ΔC produces a urious signal given by

$$\delta(1/Q) = (1/Q)(\Delta C/C) \qquad (17)$$

mparing this with equation (7c) it can be seen that marginal cillators are $Q/5$ times (i.e. about ten times) less sensitive microphonics.

The disadvantages of marginal oscillators are threefold. stly, they are less sensitive; secondly, they are difficult to just at levels below about 20 mV; and finally they cannot used with circuits of a low L/C ratio. If the shunt pedance of the tuned circuit is low, not only is the noise ure impaired but also the circuit may fail to oscillate at all.

THE NEW CIRCUIT

All the advantages stem from the use of the same circuit the n.r. circuit and as the tank circuit of the oscillator. l the disadvantages stem from the use of one tube to ovide both regeneration and amplitude limiting. In the cuit illustrated in Fig. 5, these functions are separated. e result is an oscillator with the convenience and freedom m microphonics of a marginal oscillator, yet possessing sensitivity, range of level and freedom of choice of pedance of separate oscillator circuits.

Ideally the amplifier is linear, broad-band, low noise and h a high value of gain A with a constant phase shift, while the limiter has the characteristic shown in Fig. 6. Given these characteristics, oscillations will occur provided that

$$AV_0/V_i > GR_f \qquad (18a)$$

with an amplitude

$$V_1 = V_0/GR_f \qquad (18b)$$

Since V_1 depends linearly on $1/G$ and thus on Q, the signal voltage is

$$\delta V_1 = V_1 Q \delta(1/Q) \qquad (2)$$

and since no noise is passed by the limiter, the noise voltage at the input as seen by the detector is

$$V_n = (4kTFB/G)^{1/2}$$

Thus unity signal-to-noise ratio occurs when

$$\delta(1/Q) = \frac{1}{V_1}\left(\frac{4kTFB}{Q\omega c}\right)^{1/2} \qquad (19)$$

exactly as in Rollin's simple circuit (Fig. 1).

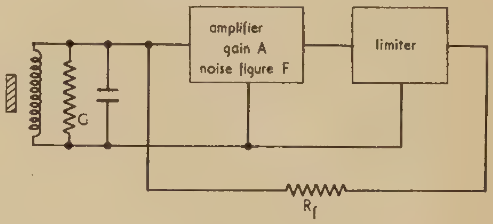

Fig. 5. Limited self-oscillator

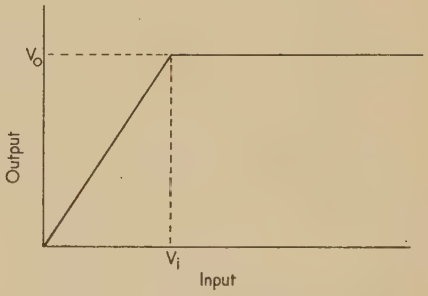

Fig. 6. Ideal limiter characteristic

Practical limiters are not ideal. They also generate noise. Let the limiter output be V_3 for an input V_2, then the oscillation condition becomes

$$AV_3/GRV_2 = 1 \qquad (20a)$$

A noise voltage V_n at the amplifier input is fed back as a noise voltage

$$V_n' = V_n(A/GR)(\partial V_3/\partial V_2) \qquad (20b)$$

Thus

$$V_n'/V_n = (V_2/V_3)(\partial V_3/\partial V_2) \qquad (20c)$$

With even very imperfect limiters, this quantity is small, less than $\frac{1}{3}$. In practice, it can be made very much less than this with little difficulty.

The most useful practical limiter is the saturated pentode. In Part 2 of this paper it is shown that the output at the input frequency is approximately equal to the mean anode current. Let this be I_0 passing through a load resistance R_L and displaying full shot noise. The noise fed into the input circuit is

$$I_L^2 = 2eI_0BR_L^2/R^2$$

The available r.f. voltage output is

$$V_L = I_0R_L$$

and the input level

$$V_1 = V_L/GR$$

Combining these equations and comparing the noise current with Johnson noise in G, one obtains an oscillator noise figure

$$F_0 - 1 = 20(V_1^2G/I_0) \tag{21}$$

With $I_0 = 5 \times 10^{-3}$ A

$$F_0 - 1 \simeq 4000\, V_1^2G \tag{22}$$

Unless one wishes to combine high level operation with a low circuit impedance, this is negligible. With $G = 1/5000$ and $V_1 = 0{\cdot}5, F_0 - 1 = 0{\cdot}2$. At lower levels it will certainly be negligible.

Thus, apart from a combination of extreme circumstances, the imperfections of practical limiters have little effect on the sensitivity. A direct experimental comparison of a circuit of this type with a separate oscillator circuit using the same coil, specimen, etc., and a level of 10 mV revealed no difference in signal-to-noise ratio, apart from the complete absence of microphonics with the limited oscillator.

Because limiting is done at high level there is, in principle, no lower limit to the level at the n.r. coil. In practice, stable oscillations with only 100 μV across the coil can be achieved without using automatic level control and without critical adjustments. Whereas in a conventional marginal oscillator circuit the level is set by a delicate balance between circuit loss and regeneration, here the level depends on th quantities in a linear way, so that small changes in regeneration do not have a disproportionate effect on level. Since low levels are easily achieved and since am regeneration is available, circuits having a very low L/C be used without either saturating the resonance or complet killing the oscillations. Thus, for example, the ^{7}Li resonan at 3·5 Mc/s has been observed in a specimen of lithi fluoride having a relaxation time of 30 s at 4·2° K, using coil tuned with 5000 pF having a shunt impedance of appro mately 400 Ω. This latitude in the L/C ratio of the circ is a great convenience in all but the simplest experimen situations.

The above theoretical considerations indicate that this ty of circuit is capable of the highest sensitivity. The practi results obtained with the circuits described in the succeedi paper show that this sensitivity is easily achieved and n vitiated by microphonics or component instability.

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Part 2. Practical design

THE LIMITER

The design hinges on the performance of the limiter. Conventional limiters used in f.m. circuits use either biased diodes or saturated pentodes. Both types of limiter are adequate for the present purpose, but pentode limiters economize in components. Therefore discussion of diode limiters has been omitted.

The basic pentode circuit is shown in Fig. 7. A radio-frequency voltage V (peak) from a source of impedance R_s is rectified at the signal grid. The steady negative voltage V_0 developed across R_g may be shown to be

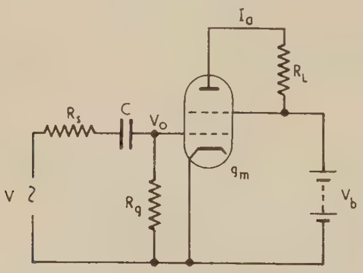

Fig. 7. Pentode limiter circuit

$$V_0 = V \cos \theta \tag{1}$$

where

$$\tan \theta - \theta = \pi R_s/R_g \tag{2}$$

and 2θ is the phase angle during which grid current flows. The table gives numerical results.

Numerical results of basic pentode circuit

2θ (deg.)	60	90	120	150	160
R_s/R_g	0·016	0·07	0·22	0·8	1
V_0/V	0·866	0·707	0·5	0·26	0·17

In Fig. 8 the behaviour of the grid voltage and anode curre during a complete cycle is illustrated. In this diagram

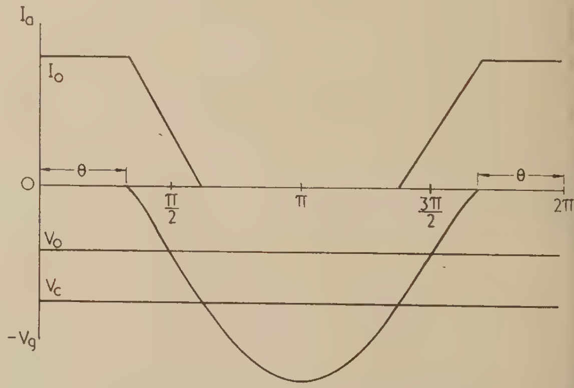

Fig. 8. Anode current and grid voltage of a pentode limiter during a complete r.f. cycle

denotes the cut-off grid voltage at which anode current ceas For a fixed value of R_s/R_g the form of the diagram depen only on the ratio V/V_c. If θ is near to $\pi/2$ and $V/V_c \gg$ the anode current consists of square pulses each lasti approximately half a cycle and having a peak value I_0 equ he anode current at zero bias. The mean current $\bar{I}$ and fundamental component I_1 are then given by

$$I_1 = (4/\pi)\bar{I} = (2/\pi)I_0 \tag{3}$$

der these conditions, i.e. $\theta \simeq \pi/2$, $R_s/R_g \gg 1$, $V_0 \ll V$ $V \gg V_c$, the output at the input frequency is independent the input V. If θ is reduced by increasing R_g limiting urs at lower values of V, e.g. when $V \sim V_c$, but at higher ies of V the limiting action is over-effective and the output reases with increasing input. In practice, measurements w that satisfactory limiting over a range of inputs from

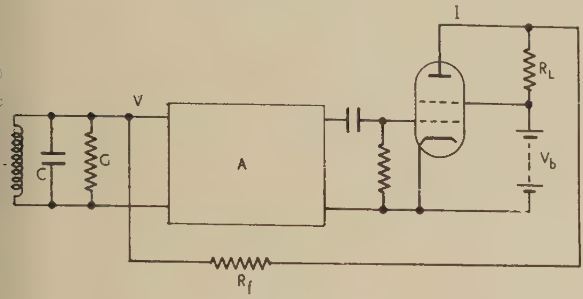

Fig. 9. Self-oscillator with pentode limiter

$< V < 4V_c$ is obtained with $R_s/R_g \simeq 0{\cdot}2$ and $V_0/V \simeq$, $2\theta \simeq 120$ deg. A detailed analysis of the circuit is possible tedious, and for this purpose unnecessary since only a y moderate limiting action is required.

he cut-off voltage of short grid base pentodes, such as type 6AK5, is of the order of 4 V with the normal screen tage (150 V). By reducing this to 25 V or less, V_c can reduced to about 0·5 V.

GENERAL DESIGN

uppose, then, that one wishes to build an oscillator to rate at a level V volts. Satisfactory limiting requires an ut of the order of V_c volts at the limiter. The gain A he preceding amplifier must therefore be:

$$A = V_c/V \tag{4}$$

Now consider the circuit shown in Fig. 9. Let A be sen so that at the lowest desired level of oscillation V', $'' = V_c'$ where V_c' is the cut-off voltage at a supply voltage V_b', and let R_f be adjusted to maintain oscillations at this level. Then if V_b is increased to $V_b'' = aV_b'$, V_c is increased in the same ratio. The peak anode current and the output of the limiter are also increased. If this, too, increases in the same ratio a the whole circuit will oscillate at a level $a\,V'$. Conditions at the limiter will remain unchanged. In practice, the limiter output increases at a greater rate than a and so the level rises more than a times and the voltage at the limiter grid exceeds V_c''. Fortunately, adequate limiting occurs over an eight-to-one ratio of input to cut-off voltage and the circuit will accommodate this change.

If R_f is chosen so that, at the lowest desired level and the lowest possible supply voltage V_b, the level at the limiter is of the order of $\frac{1}{2}V_c'$, then approximately a 20 : 1 change in level can be effected simply by increasing V_b. The adjustment of R_f is most easily carried out by making R_f equal to one-third of the value which just sustains oscillations. An error of 2 : 1 in R_f makes little difference to the performance.

Since V_c' is of the order of 0·5 V, the gain of the amplifier must be approximately 25 if levels between 20 and 400 mV are required, and 1000 if levels down to $\frac{1}{2}$ mV are required. The oscillator must contain an even number of valves (including the limiter) to preserve the correct phase of the fed-back voltage. With modern pentodes a gain bandwidth product of approximately 200 Mc/s is possible. Thus a three-stage amplifier will give a gain of 1000 over a band of 20 Mc/s, while a single-stage will give a gain of 25 over a band of 8 Mc/s. If it is feasible to provide some sort of coarse tuning of the interstage circuits these bandwidth figures can, of course, be increased.

TWO PRACTICAL CIRCUITS

The precise form of the circuit depends on the particular application. The two circuits described here were designed: (1) to give levels between 10 and 200 mV at frequencies between 20 and 60 Mc/s with some coarse tuning of the inter-stage circuit; and (2) to give levels between 1 and 250 mV at frequencies from 200 kc/s to 20 Mc/s with no tuning adjustments.

The first circuit is shown in Fig. 10. The first stage V_1 uses a type E180F pentode having a mutual conductance 16·5 mA/V with input and output capacities of 11·5 and 3·5 pF. The limiter V_2 uses a type 6AK5 (chosen primarily

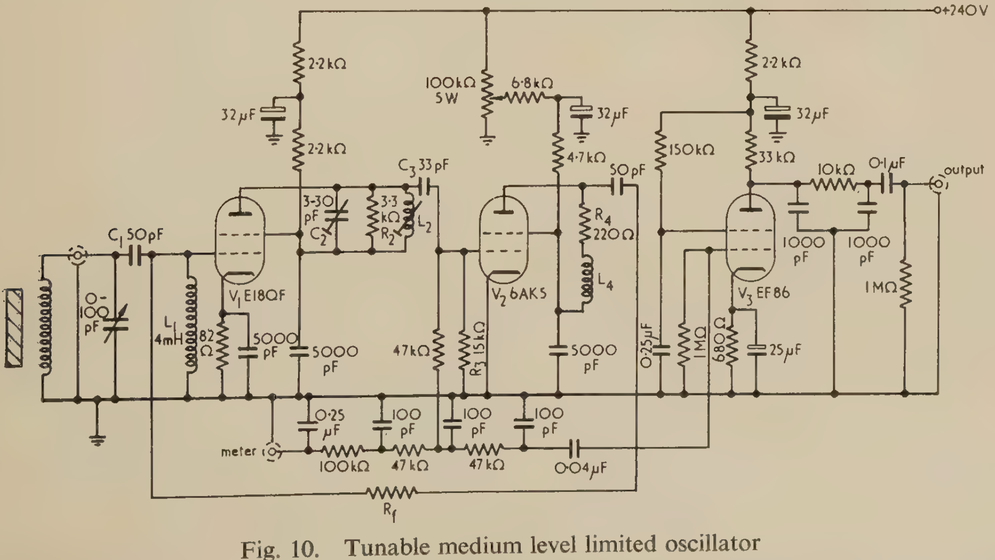

Fig. 10. Tunable medium level limited oscillator

for its low input capacity of 4 pF). The anode load of V_1 is tuned by L_2 (which is permeability tuned) and C_2 (3 – 30 pF). With C_2 at its minimum setting, a gain of 50 over a 4 Mc/s band is achieved without retuning; L_2 is wound to resonate with $C_2 = 3$ pF, together with the valve capacities (8 pF) at 63 Mc/s at its minimum setting. With C_2 and L_2 at maximum, the resonant frequency is 17 Mc/s. A coverage of 15 to 65 Mc/s is thus achieved.

The capacitor C_1 (50 pF) and the r.f. choke L_1 (4 mH) remove direct field modulation pick-up. The choke is wound astatically, i.e. it consists of two well separated pies (at the opposite ends of a $\frac{1}{2}$ W resistor) connected in opposition. This minimizes direct pick-up in the choke itself.

The grid leak time constant C_3 (33 pF), R_3 (15 kΩ) is chosen low enough to prevent squegging (discontinuous bursts of oscillation) at the highest frequency. If this is f and the coil has a quality factor Q then, roughly speaking,

$$fCR < Q \qquad (5)$$

Since the signal is rectified at the limiter grid it seems only sensible to use the rectified signal thus produced both as the output and to monitor the level. The network shown filters out the r.f. without increasing the grid leak time constant. A level of 20 mV provides a rectified voltage of $50 \times 0{\cdot}02 \times \frac{1}{2} = \frac{1}{2}$ V and thus gives a meter current of 2·5 μA. The final stage V_3 is a conventional low-frequency amplifier included on the same chassis to minimize pick-up in the leads.

The limiter grid current flows through R_3. If one assumes that this displays full shot noise, the resulting noise voltage across R_3 is

$$V_n^2 = 2eI_gR_3^2B = 2eV_0R_3B$$

In terms of Johnson noise this is

$$V_n^2 = 20V_0 \,.\, 4kTR_3B$$

The ratio of this noise voltage to amplified Johnson noise from the tuned circuit is (allowing for 50% detection efficiency)

$$F^1 = 80V_0R_3/A^2Z \qquad (6)$$

where A is the amplifier gain and Z the impedance of the tuned circuit. With $V_0 = 3$, $R_g = 15 \times 10^3$, $A = 50$, $Z = 5 \times 10^3$, this is unity. This value of V_0 corresponds to a level of 120 mV, so that noise from this source is import at the higher levels. At 200 mV the overall noise figure is while at 10 mV it approaches unity. This deterioration sensitivity at high levels could, of course, be avoided by us a separate diode detector.

The anode load of the limiter R_4, L_4 calls for some co ment. It is unnecessary for the limiter to provide gain. T load R_4 is therefore made low (220 Ω) to give a wide frequen range. The inductance L_4, which tunes with the va capacity at 110 Mc/s, is included solely to provide ph compensation at the higher frequencies. Direct current used for the heater supply.

The second circuit (Fig. 11) uses a three-stage amplifi The audio-stage is omitted from the diagram. The fi three stages again use type E180F valves chosen for th high gain bandwidth product. The limiter V_4 is a ty 6AK5. The choke L_1 is 10 mH, again astatically woun and the limiter grid leak time constant is chosen to avo squegging at 20 Mc/s.

The arrangements for monitoring the level and taking the detected signal remain as before, but now, because of t increased gain, grid current noise is unimportant. The loa of the first three stages are tuned with the valve capacities resonate at 28 Mc/s with a Q of $1/\sqrt{2}$. This requi $R_2 = R_3 = 560\ \Omega$, $L_2 = L_3 = 2\ \mu$H since the circuit capac is 15 pF. The input capacity of the limiter is less (4) th that of the amplifier tubes (11·5) and so $L_4 = 4\ \mu$H a $R_4 = 1$ kΩ ($C_4 = 8$ pF).

A circuit resonant at f_0 with $Q = 1/\sqrt{2}$ has the proper that its impedance is sensibly constant up to $f_0/\sqrt{2}$. T gain of the amplifier is therefore constant at 1400 up 20 Mc/s. Measurements show a variation of ±20%. T phase of the r.f. voltage, however, is shifted as the frequen increases. The shift reaches −110 deg. at 20 Mc/s. This partially compensated by tuning the limiter load at 28 M with a Q of 3. The remaining phase shift is further reduc by the use of the R_fC_f feedback network, chosen so th $R_fC_f \simeq 1$ at 20 Mc/s. With $R_f = 1$ MΩ this requi $C_f = 0{\cdot}01$ pF, which is obtained by placing two wires proximity to each other.

The lower frequency limit is determined by the intersta coupling capacities; 200 kc/s was chosen rather arbitrarily the lowest frequency likely to be of interest.

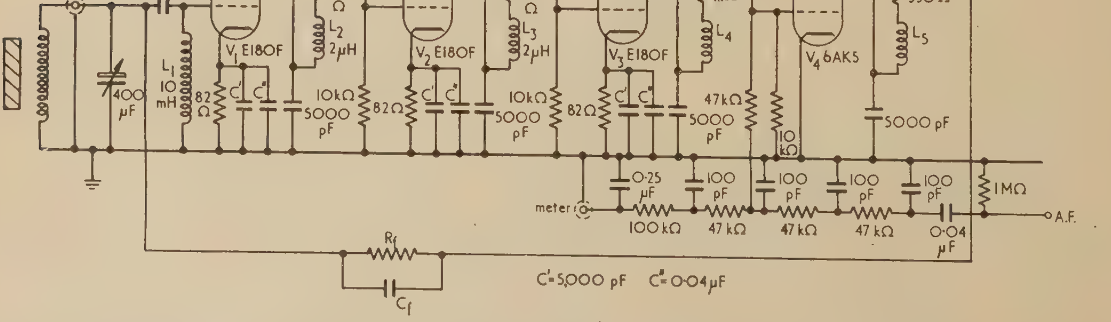

Fig. 11. Broad band low level limited oscillator

n oscillation level of 1 mV produces 1 V rectified at the er grid and 5 μA meter current. This can be checked onnecting a low-impedance signal generator in place of resonance coil. Measurements of the limiter output v that with varying supply voltages, satisfactory limiting chieved when the meter current lies between 2·5 and A. At a fixed supply voltage the range of tolerable ting encompasses a range of 5 : 1 in input level. The edure for adjusting R_f is therefore to choose a value ng 2·5 μA at the lowest limiter supply voltage; C_f is trimmed if the frequency is above 15 Mc/s to ensure oscillation can be maintained at 20 Mc/s. Too small a e of C_f is indicated if the oscillations become excessively y, or if changes in the level setting pull the frequency ssively.

he noise resistance of a pentode-connected type E180F is 500 Ω. The noise figure therefore increases if the uit impedance is below 1000 Ω. However, this problem ommon to all n.r. circuits. By reducing R_f, circuits having edances of only 100 Ω can be made to oscillate, and it is sible to cover 18 — 3 Mc/s using the same coil, merely by ing tuning capacity.

RESULTS

o attempt has been made to measure the sensitivity of uit 1, but a direct comparison of circuit 2 has been made a separate oscillator circuit. The test was made at c/s using the ^{7}Li signal from lithium fluoride at 4·2° K. level was set at 10 μA (2 mV) and the signal-to-noise o estimated on an oscilloscope using a 50 c/s, 30 G sweep. feedback resistor R_f was then removed and a standard ial generator connected through a high resistance to the ut. The output was adjusted to give the same meter ding and the signal-to-noise ratio again measured. The ial and noise were the same (ratio approximately 5 : 1) in the accuracy of the measurement (50%), although n with the most careful tuning of the generator, the second ervation was rendered extremely difficult because of rophonics. These were completely absent using the self-illator. This measurement shows that the oscillator uit in itself does not introduce noise. In both cases any se in excess of Johnson noise was solely due to the plifier noise figure.

he circuit appears to be remarkably free from micro-nics. In one experiment the whole apparatus was visibly king due to vibration from a pump, but the signal remained fectly steady.

photograph of the complete circuit is shown in Fig. 12 h the outer case and base plate removed. All the com-nents are mounted on a single circular chassis and grouped und the tuning capacitor which is enclosed in the central eening can. Standard miniature i.f. transformer formers used for the inductances L_2, L_3, L_4, L_5 and the r.f. leads kept short by taking all d.c. leads, such as heater and een supplies, directly through the chassis and out of the at the valve bases. Insulated $\frac{1}{2}$ W resistors make excellent ulated lead-throughs. Apart from careful location and entation of the valve sockets, no attempt is made at eening or heater filtering; nevertheless, the circuit is stable h R_f removed. The tuning dial and sockets are located the top plate (also circular) and the whole assembly fits de a cylindrical can and is completed by screwing on a e plate. This carries a clamp for securing the lead to the coil.

The circuit as it stands covers levels from less than 1 to 15 mV. At the latter level the third amplifier tube overloads. The range can be extended upwards by five times by removing the cathode bypass capacitors on V_3. The gain is reduced by 2·3. A further increase in level can be made by performing the same office for V_2 and then V_1. With all bypass capacitors removed the overall gain is approximately 100 and the maximum level approximately 300 mV. Of course, adjustment of R_f must be made at the same time.

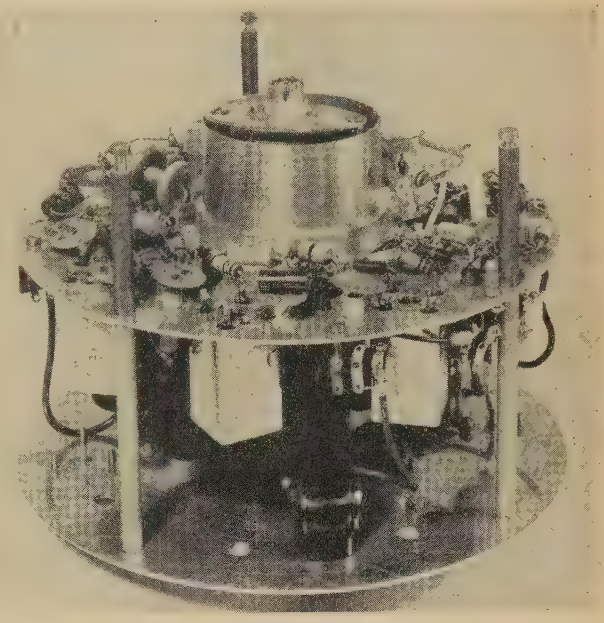

Fig. 12. The broad band, low level circuit of Fig. 11. The first r.f. stage is on the left below the non-inductive r.f. choke. The limiter is on the right below the length of stripped coaxial line forming C_f

It is perhaps worth remarking that the circuit contains no more components than are necessary to build a receiver to detect n.r. signals at the same level. None of the component values are critical, with the possible exception of the phase-correcting circuits L_5 and C_f at frequencies above 15 Mc/s. If it oscillates and if the limiter voltage controls the level, the sensitivity is little improved by adjusting R_f.

NOTES ON THE COMPONENTS

The tuning capacitor is Jackson Bros 200 + 176 pF connected in parallel. The astatic chokes are made by removing two pies from standard Bulgin short wave chokes and mounting them on 1 MΩ, $\frac{1}{2}$ W resistors. All bypass capacitors, with the exception of the 32 μF electrolytics and the 0·04 μF metallized paper cathode bypasses, are ceramic. All resistors are $\frac{1}{2}$ W insulated carbon, except those in the network leading from the limiter grid, the anode loads and R_f, which are $\frac{1}{4}$ W uninsulated. All the valves, except the self-screened audio-stage, have screening cans. The i.f. coil formers are 0·3 in. diameter, 1 in. long in $\frac{7}{8}$ in. square cans, and have permeability tuning slugs. A standard Belling–Lee television coaxial plug and socket are used for the connexion to the n.r. coil.

Compact calorimeter for measuring the overall thermal efficienc of freestanding fires and stoves for room warming

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[*Note first received* 25 *March, and in final form* 5 *August*, 1959]

The heat output by convexion and radiation of a modern solid fuel room heater is best measured by a calorimeter absorbing all the heat. By using a comparatively small water cooled box enclosing the heater good absolute accuracy and rapid response can be obtained and the heat output should not differ by more than 1% from that in an average large room. Such a box can be simply constructed from insulated "tube-in-strip" and the air flow in and the rate of loss of weight of fuel in the heater can be continuously measured.

COMPARISON OF DIFFERENT METHODS

Methods. The factors affecting the efficiency of the simple domestic open fire without any heat-transfer arrangements additional to fuel-bed and flame radiation have been fully investigated by the Fuel Research Station, B.C.U.R.A., the Gas Council, and other interested bodies.(1,2) The effect of type of fuel, opening of the radiant space, arrangement of the grate, and control of underfire air have been fully investigated for the simple open fire. Future work should be devoted to those types of convector fires and open/close stoves that supply an appreciable proportion of the heat of the fuel to the room by natural convexion around metal parts of the stove, which thus provides heated air to the room as well as direct radiant heat from the fuel surface and the flames. As long as studies were primarily focused on the simple open fire, methods of measuring radiation alone(3, 4) were satisfactory although, even with the open fire, there was a certain amount of convective heating of the room air from the chimney breast.

There are, at the present time, three methods which aim to measure the overall efficiency of heat output of freestanding convector fires and open/close stoves by adding together the heat transferred to the room by convexion and by radiation. These are given below.

(1*a*) The large room cabinet used by the Fuel Research Station,(5) in which the heat flowing to the walls of the room is obtained by a series of differential thermocouples measuring the heat flow through the walls when a steady state has been reached.

(1*b*) The large room, air cooled, calorimeter of B.C.U.R.A.(6)

(The essential principles of these two are both illustrated in Fig. 1(*a*) as far as heat flow and air flow within the room are concerned.)

(1*c*) The miniature-room water-cooled calorimeter proposed in the present paper [Fig. 1(*b*)].

(2) The use of a hood over the fire for measuring convexion, and a radiometer for measuring radiation [Fig. 1(*c*)].

(3) The flue-gas loss method.(2)

In Fig. 1(*a*), the arrow, 5, represents the metered air flowing into the room, which usually varies over the range 500–6000 n ft 3/h for an opened stove, while the stove is burning solid fuel over the range $\frac{1}{2}$–3 lb/h. The theoretical quantity of air needed for burning these amounts of coal is about 65–390 n ft 3/h, so that there is always a very large excess of air, and the carbon-dioxide content of the gas flowing up the flue (arrow 8) is very low. For a closed stove, the air flow is much lower for a given rate of fuel bur and the carbon-dioxide in the flue gases can be as hig 10–14%. Arrow 10 refers to the flow of heat from the w to the incoming air, a flow which plays no part in the exte heat balance because this heat does not leave the syst directly. This heat flow in fact amounts to a reduction of net heat flow, arrow 6. Arrow 1 represents the combus air and excess air flowing into the stove, 9 represents the drawn from the room by natural convexion passing thro the essentially tubular space of the heater (that is, spa which are bounded by metal of the heater) on both si whether they are a space between the inner and outer c iron casing of a stove or the back space of a convector or a special heating flue, while 3 represents the part of room air which circulates on the free outer surface of stove, and is heated to a much less extent. The stream warm air 9 and 3 joined together, flow in a closed cir round the room giving up some heat by convexion to walls of the room (as shown by 6), and then return to mi with the air entering the room at 4. This mixture t divides into the stove air 1 and the further recirculated 3 and 9. Arrow 7 represents the direct radiation from stove to the walls. The dotted line 2 represents a man piece or overhanging recess roof which, in many pract installations, affects the air flow 3, although it is unlikely have any effect on the air flow 9.

Mechanisms of heat transfer in different systems. above statement of the factors affecting heat transfer in large room, which may be regarded as describing th for one type of room in which the stove will be used practice, enables us to make a simple theoretical compari with the factors affecting heat transfer in the small-ro calorimeter, and in the hood-and-radiation system. As as the small room is concerned, the radiant heat 7 [Fig. 1 from the stove will be absorbed to exactly the same ext in the small room as in the large one, provided the in surface of the small calorimeter is blackened to give it a h emissivity. This is necessary because the inner surface no longer be assumed to be infinitely large compared with stove, and a significant fraction of reflected heat wo return to the stove if the inside of the calorimeter had got a high emissivity.

As far as convexion is concerned, it can be said at once t the size of the room will make no difference whatever to amount of air and the temperature rise of the air circulat through the internal heating surfaces 9 of the stove. T follows because the overall temperature of the air reach the stove is primarily governed by the overall flow of through the system, which can be made identical in bo calorimeters by using similarly insulated flues, and beca the flow resistance and heat transfer conditions for

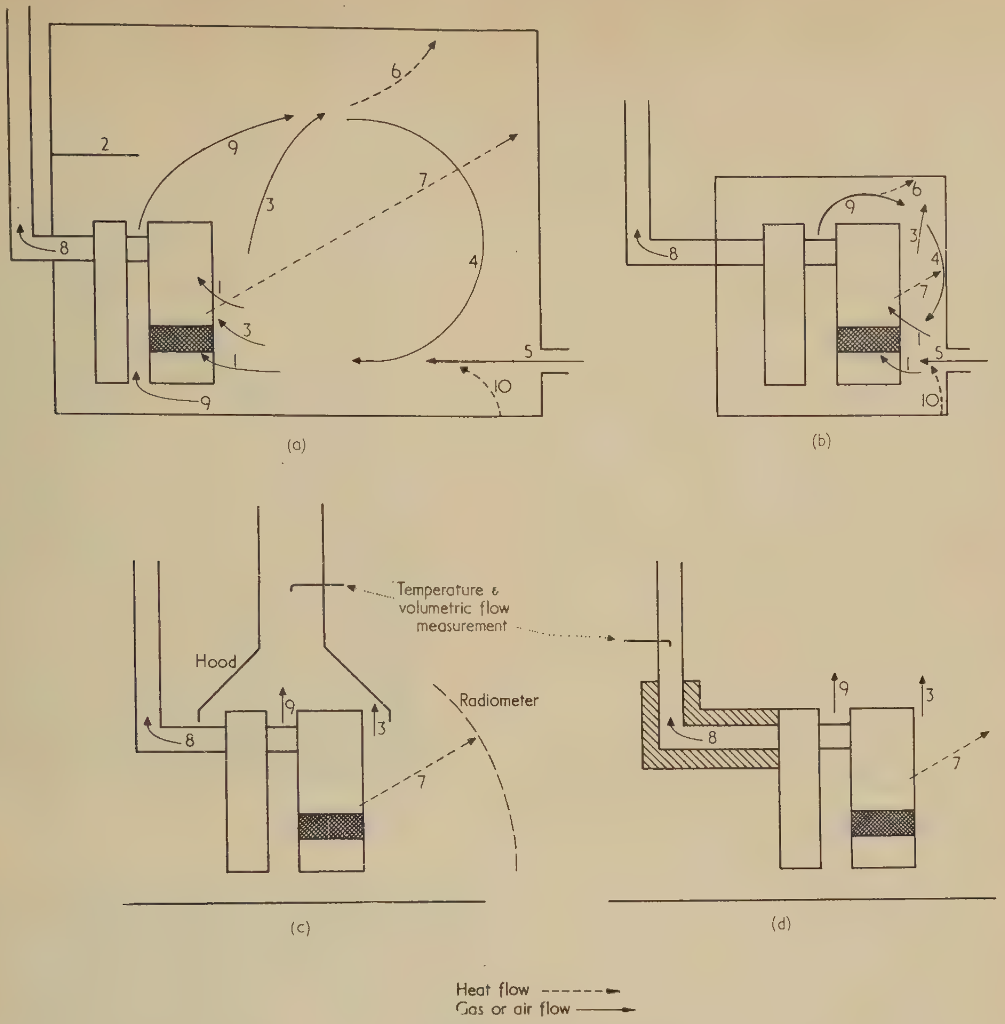

Fig. 1. Diagrams of heat-transfer mechanisms in various types of fire and stove calorimetry

(*a*) Stove in large calorimeter room; (*b*) Stove in miniature calorimeter room; (*c*) Principle of hood and radiometer method; (*d*) Flue-gas less method.

rnal heating surfaces will obviously not be affected by the
of the room which is in any case remote from the stove.
v, most modern high-efficiency free-standing stoves and
have air-heating surfaces which are bounded on both
s by parts of the stove or parts of the room which are
e to the stove. In these stoves, it is probable that more
three-quarters of the convective heat transfer occurs at
e surfaces, and less than one-quarter at surfaces open to
remote walls of the room. As far as these outer surfaces
concerned, no work can be traced on free natural con-
on from a vertical hot plate in a small and large enclosure,
even if it had been done for a closed system, the present
em where there is a very large air flow from the outside
ugh the system would be expected to be less influenced
oom size because the main air temperature is affected
only by the heat transfer, but also by the overall flow of
hrough the system. On the Continent, a standard method
esting the efficiency of hot-water radiators (that is, con-
ve heating systems), is to use a small enclosure,(7)
ough it is considered that in this case the natural con-
on may be somewhat affected by the enclosure. If,
efore, it is assumed that, because of the use of a smaller
n calorimeter, there might be a 20% reduction in the
exion coefficient for the convexion from the outer
surface 3, then, as this affects only one-quarter of the effective heat transfer, the overall convexion will be in error by only 5%. This 20% assumption is certainly an upper limit, and obviously the presence of a mantelpiece or recess roof, as indicated by 2 of Fig. 1(*a*) would have a much larger effect. Further, if allowance is made for (1) the compensating effect of the air flow through the system, which tends to make the rise in air temperature identical for both systems when there is the same air flow and the same heat output from the stove, and (2) the fact that the surface temperature of the stove will be slightly hotter if there is a reduced convective heat transfer from it, it seems likely that this 5% error will come down to 4%. Because the convexion component is usually of the order of 25% of the thermal input to the stove, the overall effect of going from a large room to a small room calorimeter is not likely to be more than a unit of percentage, an amount which is considerably less than the absolute accuracy of the methods.

The method [Fig. 1(*c*)] using the convective-hood and radiation measurement, has the advantage of giving the convective heat output and radiant-heat output of the stove separately, but is obviously not such an accurate method as those in which the whole heat output of the stove is integrated by enclosing it in a cooled box, especially as it is much more difficult to ensure that the convective air flow is completely undisturbed by the arrangements for measuring it. This method also essentially requires a measurement of the volume or mass of air flow as well as the temperature rise of the air, so that errors are almost unavoidable. In the flue-loss method [Fig. 1(*d*)], it is necessary to have an accurate measurement of the mass of gas flowing up the flue, and of its composition and temperature, and accuracy is difficult to attain because of stratification in the gases going up the flue. If great precautions are taken to mix the gases fully, then they will be associated with an appreciable heat loss which is admitted(2) to make this method unsuitable for absolute efficiency determinations.

Absolute accuracy and repeatability. Both the large and the small calorimeter room can be calibrated by sealing off the air inlet and flue exit and liberating a measured amount of electric energy in the room. At first sight, therefore, the fact that the water calorimeter with good lagging on the outside is in itself an absolute instrument and gives a calibration factor of about 0·98 (which is within the accuracy of the measurement of the rise in water temperature) would appear not to be a very great advantage. However, it is a considerable advantage because a system based on heat flows through plywood walls is always susceptible to changes in the thermal characteristics of the walls, and its calibration must therefore be continually checked. A system based on air as the calorimetric fluid has the inherent disadvantages that leaks cannot be seen and that accurate measurements have to be made of the mean rise in temperature and rate of flow of the volume of air that must be circulated. The calibration of a water-flow meter can be checked by running the water into a measured volume at any time, whereas the calibration of an air-flow system is not at all a simple matter.

Time-lag. In a constant-flow calorimetric system, the time-lag is, in effect, dependent on the sum of the "dwell time" of the calorimetric fluid in the walls of the system, together with the time required to bring to the new temperature the part of the enclosing metal structure that changes in temperature when the heat output of the apparatus changes. This time is obviously proportional to the mass of metal multiplied by the mean temperature rise and divided by the rate at which heat falls on the wall. Both these time factors can be kept to a very low figure by using a rapid flow of fluid with a high heat capacity, so that very small temperature rises are obtained even at the highest output. This makes water almost the ideal fluid for a small-time-lag system, and also means that a small calorimetric cabinet will necessarily have a very much shorter time-lag than a large one for the same heat output rate of the stove. The method based on heat flow through the walls is bound to have a much longer time-lag because it depends on the thermal diffusivity of materials and this system has a time-lag of the order of nine hours. The water-cooled system has a time-lag of less than ten minutes, because the total dwell time of the water in the system is only of the order of two or three minutes and none of the metal of the calorimeter rises more than 3° C above the water temperature, even for the maximum heat output of the stove, while the overall water temperature rise is also limited to about 3° C, a rise which can readily be measured accurately for water.

THE DESIGN OF A WATER-COOLED CALORIMETER

Mark I calorimeter. Fig. 2 shows the Mark I water-cooled calorimeter constructed from rectangular drawn-brass tube, while Fig. 3 shows it with the doors open and with a stove alight in it. The system is arranged to give a water t perature rise of 3° C when it is testing a stove of maxim output (that is, one burning 3 lb of coal per hour wit thermal efficiency of 80%). Under these conditions, water-flow rate is 215 gal/h and the dwell time of the wa in the system is 1·05 min. A multiple differential therr couple system has been developed to give an output of 0·5 n which is connected directly to a recorder. The calorimete made airtight by having the openable face closed tightly o tube-rubber seal. This face is connected to the water cir by flexible rubber hose, which can be seen in Fig. 2. The entering the calorimeter is metered by one of a pair venturis (designed by J. M. Beer) of special shape, the lar one of the pair giving a differential head of $\frac{1}{20}$ in. w.g. 3000 ft^3/h and the smaller a differential head of $\frac{1}{20}$ in. v at 600 ft^3/h. In well-designed venturis, the overall loss head for these rates of flow is only about one-quarter of

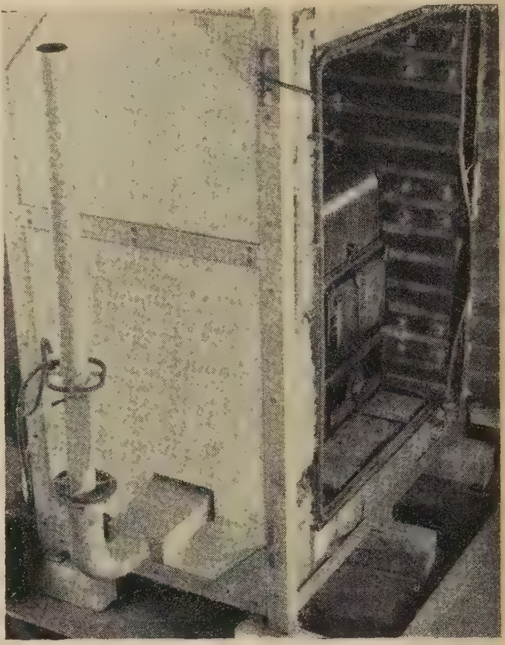

Fig. 2. Mark I calorimeter

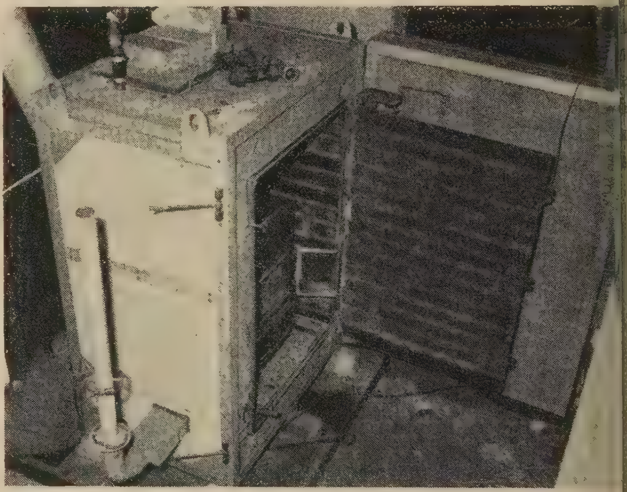

Fig. 3. Mark I calorimeter with door open

erential pressure. The stove is connected to an external by a horizontal 5 in. pipe sealed through the back wall about 3 in. of it exposed to heat transfer inside the rimeter.

he curves for rise of temperature of the water outlet r a 3 kW electric heater was rapidly inserted, and the when it was switched off are shown in Fig. 4. The sured heat to the calorimeter was 98% of the electrical t input.

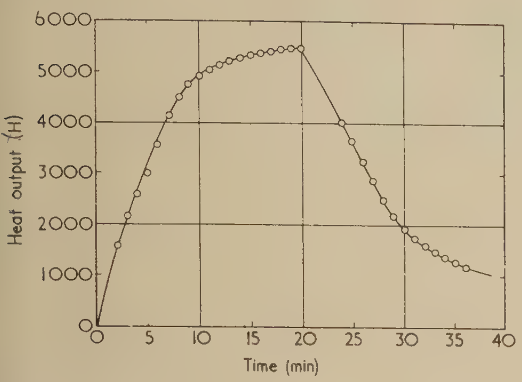

Fig. 4. Variation of heat output with time

ark II calorimeter—Tube-in-strip calorimeter with con- ous measurement of weight loss. Each face of the calori- er has to be not only watertight for the flow inside, but ight as an overall face, and this made construction from angular brass tube somewhat elaborate. However, since design of this instrument, I.C.I. Metals have produced r "tube-in-strip", and experiments have shown that this erial in copper can be much more readily constructed a calorimeter using tubes of ½ in. bore spaced on 3 in. tres. This is lighter and more airtight, and also reduces weight of water very much. The construction of the er-cooling box for such a system by silver-soldering is wn in the photograph of Fig. 5. An integration of the heat flow across the space between two tubes indicates that the temperature difference for a given rate of heat transfer will depend on the square of the distance apart, but normal values for the conductivity of the copper gives, for the maximum rate of heat transfer, a temperature difference between the water and the centre of the strip between the two tubes of only 1° C. The heat capacity of the system for such a temperature rise amounts to the heat output of only a few seconds, so that the time-lag from the point of view of the metal will not be longer than that of the Mark I calorimeter; the water capacity is considerably less so that the same flow of water will go through in a very much shorter time.

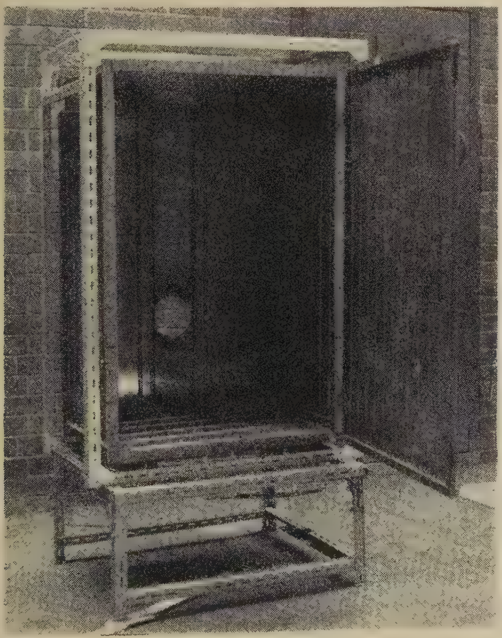

Fig. 5. Construction of water-cooling box

Four vertical open tubes are being arranged through the floor of the calorimeter box and of the lagging so that the appliance can stand on legs through the tubes resting on the pan of a scale, and the rate of burning of fuel can be measured constantly, and a heat balance carried out every ten minutes. This takes full advantage of the rapid response of the calorimeter, but requires the use of very thin polythene tubes for air-sealing around the legs and of a soft polythene cylinder making a seal between two large disks one on the part of the flue fixed to the stove and on the part fixed in space without overheating the polythene or causing restraint on the weighing.

CONCLUSIONS

It is recommended that a compact, water-cooled, miniature calorimeter constructed approximately on the lines of the Mark II calorimeter described in this paper should be considered for adoption as a standardized piece of equipment for the measurement of thermal efficiency and total heat output of small freestanding domestic heating appliances. The advantages claimed for it are:

(*a*) Because water is used as a coolant, the absolute accuracy of measurement is high, and instantaneous checking for temperature errors and for leakage is facilitated.

(*b*) The time-lag of the calorimeter can be kept down to two or three minutes;

(*c*) The instrumentation is direct and simple.

(*d*) If the weight of the fuel burnt is measured continuously it is possible to do a short-period heat balance, in addition to a long-time one; this makes the calorimeter convenient for research on the development of high-efficiency appliances, as well as for their standardized testing.

ACKNOWLEDGEMENTS

Mr. Keith (Chatwins Ltd.) organized the design and construction of the Mark I calorimeter and Mr. A. S. Carrick, a third-year student in the Department of Fuel Technology and Chemical Engineering, University of Sheffield, carried out the measurements on this calorimeter.

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Multi-channel photoelectric scanning instrument for sizing microscopic particles

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Development of a photoelectric scanning instrument for counting and sizing particles dispersed on a microscope slide has continued and the performance of a five-channel version has been assessed. The size distributions of a number of fractions of coal particles of sizes down to 1·5 μ determined by the instrument agree (to within 15%) with those from visual counts. Comparative sizings are given also of alumina particles (5 to 20 μ) and of transparent profiles in an opaque film (5 to 20 μ). Comparative counts are given of the number of particles 1 to 5 μ in thermal precipitator samples of coal. Data are presented on the reproducibility of instrument sizings and an indication is given of the time needed for a determination.

1. INTRODUCTION

It is frequently necessary to estimate the number and sizes of microscopic particles. In recent years many attempts have been made to develop automatic methods of doing this by combining mechanical scanning with photoelectric detection and high-speed counting devices. Developments in this field have been reviewed by Morgan.(1)

The design and construction of one such instrument for sizing particles dispersed on a microscope slide have been described by Hawksley and his co-workers.(2) Although the instrument was of flexible construction to allow various scanning methods to be studied, only track scanning by a slit was investigated, the theory given by Hawksley(3) being confirmed. Since this theory requires for its simplest practical application that the particles be of constant optical density these workers confined their attention to the sizing of coal particles.

The present paper describes further investigations with an instrument of this type (Fig. 1). Changes to the construction that have been made include the introduction of a newly-designed lamphouse and illuminating system and of a spring-mounted stage which enables a higher scanning speed to be
attained and, thereby, fuller use to be made of the speed
response of the electronic circuits. The resolution of th
circuits has been improved and a photomultiplier cell hav
better output-to-noise characteristics is now used. Ex
discriminating and scaling units have been added making
possible to size at up to five different levels simultaneous
A control unit has been developed to give automatic rever
of the stage after a fixed number of traverses and stoppa
of the stage on return to its starting position, and to provi
gating of the scaling units so that they do not record
times when the stage is changing its direction of motion.

The investigations with the instrument have been direct
towards—(1) counting and sizing a variety of powders
comparison with visual determinations and (2) assessing t
reproducibility of instrument sizing and the contribution
various factors to the random error.

The performance of the instrument must be considered
relation to that in visual sizing. Even in the counting
particles as uniform in size and shape as red blood ce
appreciable personal errors can occur. For instance, Big
and Macmillan(4) found an inter-observer coefficient
variation of 3·1%: they reported in addition a rando
counting error of 7·8% when some 450 cells were count
per determination. In an experiment in which irregu
profiles on hand held test cards were judged against opaq
and transparent reference circles, Heywood(5) found a ran
of 15·5% in the estimates of mean size by 10 observ
when the opaque circles (placed adjacent to the profile bei
sized) were used and of 4·9% when the transparent circ
(superimposed over the profile) were used. The over
mean estimate of size was 5·7% high with the opaque circ
and 1·9% high with the transparent ones. In routine sizi
the errors can be expected to be higher as the particle imag
and the reference circles are not then superimposed or plac
adjacent to each other when the comparison is made. Wats
and Mulford(6) in a more satisfactory arrangement used t
profiles which were observed through a low power micr
scope, a globe and circle reference graticule being mount
in the eyepiece in the normal manner. Nine observers show
biases ranging from −17% to +13% in their estimates
the mean size of the profiles and there was a mean differen
of 2·3% (not a random counting error) between rep
determinations by an observer. For the difficult case
thermal precipitator samples much larger variations ha
been reported. In one set of tests,(7) the mean counts
9 observers drawn from different laboratories varied fro
310 to 840 particles/cm^3 of sizes 1 to 5 μ, the standa
deviation of an operator's mean counting level being 1
particles/cm^3 (3·2%). Further tests subsequent to discussio

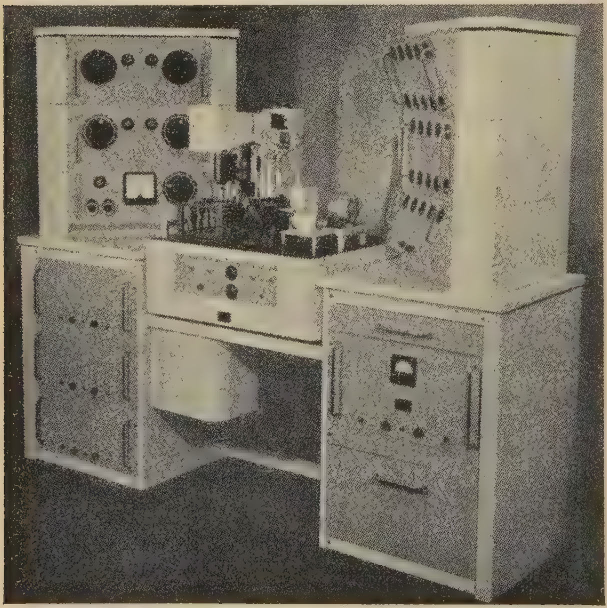

Fig. 1. Multi-channel photoelectric scanning instrument

ween the observers reduced the discrepancies considerably hout any definite reason being shown.

2. METHOD OF COUNTING AND SIZING

he method of counting and sizing is that of track scanning a slit moving perpendicularly to its length (see Fig. 2); it lds a measure of the number per unit area of particles of es greater than a series of selected sizes z_1, z_2, etc., which termed the sizing levels. Observation is made of the mber $\phi(w, z)$, per unit length of track, of particles that ch into a track of width w by distances h greater than a cified sizing level z. The theory relating this number to number and size distribution of particles has been given Hawksley.[(3)] Here it is sufficient to note that for $z =$ con- nt

$$\phi(w, z = \text{constant}) = (w + \bar{z} - 2z)NF(z) \qquad (1)$$

where $NF(z)$ is the number per unit area of particles oversize z, and $\bar{z}$ is the mean size of this oversize fraction. If the specimen is scanned repeatedly using a track of different width each time, but maintaining a constant sizing level z, the counts obtained are linear with respect to the track width w. The concentration $NF(z)$ of particles oversize z is given by the slope of the plot of count $\phi(w, z)$ against track width w;

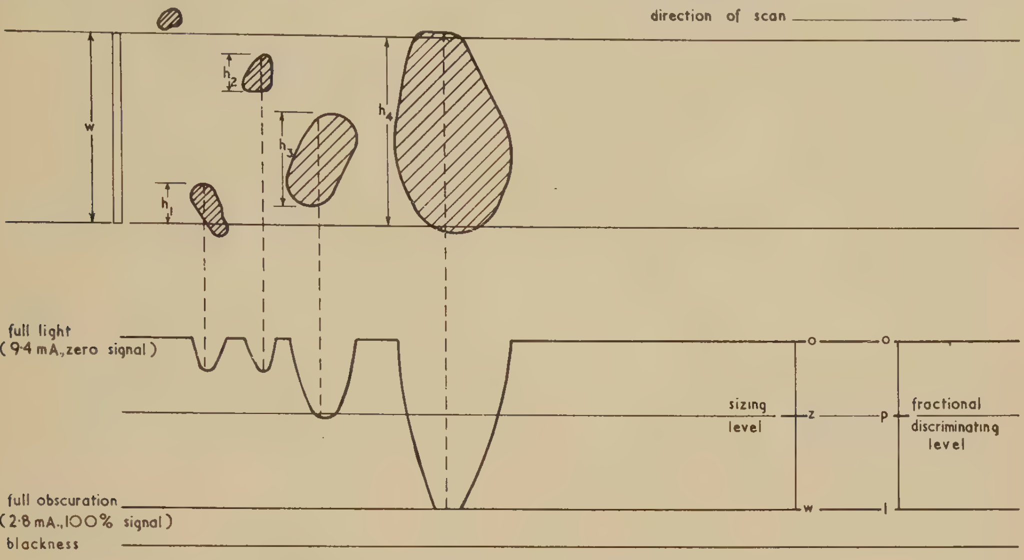

Fig. 2. Pulse heights in track scanning by slit

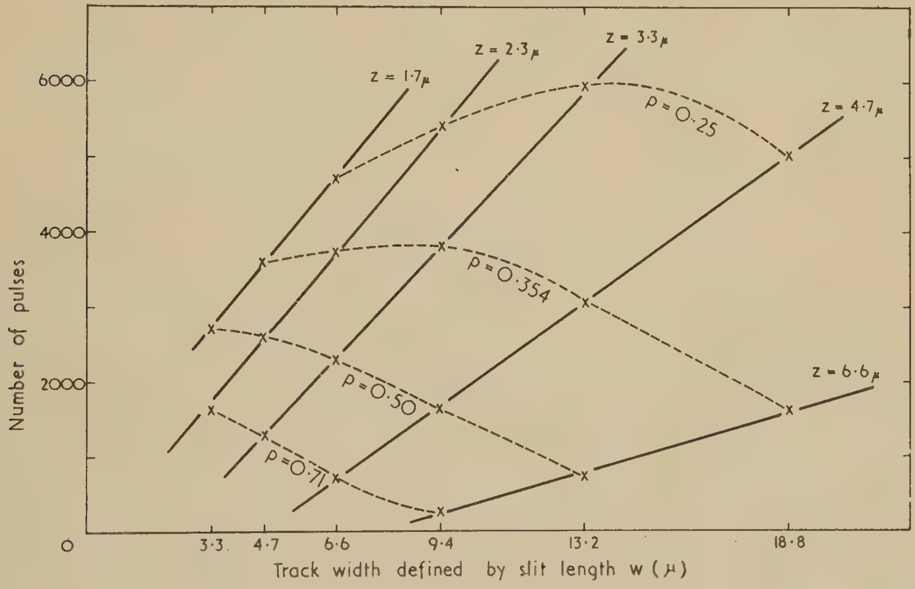

Fig. 3. Plot of pulse counts in an instrument sizing for coal (fraction 3)
Track length $L = 200$ cm.

Table 1. *Particle oversize distribution derived from Fig. 3*

Sizing level (μ) z	*Slope from graph (number of pulses per micron length of slit for scan* 2×10^6 μ *long)* $NF(z) \times L$	*Concentration of particles of sizes larger than* z *(no/mm²)* $NF(z) \times 10^6$	*Percent, by number of particles oversize* $100 \times F(z)$
6·6	140	70	23
4·7	346	173	57
3·3	544	272	90
2·3	604	302	100
1·7	608	304	100

the line, when extrapolated, intersects the w-axis at the point $2z - \bar{z}$. Repetition of the scanning at other suitably chosen values of sizing level z enables the oversize distribution of particles by number to be established (Fig. 3 and Table 1).

In operation the sizing level z is defined by means of a discriminator, which is set to respond to signal pulses of amplitudes exceeding a fraction p (the fractional discriminating level) of the amplitude of the pulse produced by a particle completely covering the scanning slit of length w. Therefore $z = pw$, and to maintain a constant sizing level z when the track width is changed it is necessary to change the fractional discriminating level also in agreement with this relationship. By having more than one discriminator, it is possible to make observations at several sizing levels (p_1w, p_2w, etc.) simultaneously.

In visual sizing, particles are usually assessed by their projected area diameters (the diameter of the circle having the same area as a particle profile). The mean size assessed by projection in a track is the somewhat larger Feret's diameter (the mean distance, for all orientations of a particle, between tangents to opposite sides of a particle, the tangents being drawn parallel to a fixed direction); for convex particles Feret's diameter is equal(8) to the perimeter diameter (the diameter of the circle having the same perimeter as a particle). The pulse amplitudes in photoelectric scanning depend for non-circular particles not on the projections in the track but on the longest chords, parallel to the length of the scanning slit, of those parts of the particles lying within the track. This means that the derived oversize distribution is one according to the "maximum chord" diameter of the particles, a diameter necessarily smaller than Feret's diameter.

3. ARRANGEMENT OF SCANNING INSTRUMENT

The essential features of the instrument are shown in Fig. 4. An illuminated iris S_1 is imaged by a microscope condenser C on the plane F of particles dispersed on a microscope slide (Köhler illumination). The object plane F is in turn imaged by a microscope objective and eyepiece on the scanning slit S_2 which acts as the field stop of the system. Behind S_2 is a lens which images the exit pupil of the eyepiece on the cathc of a photomultiplier cell. The light flux falling on the cathc generates a photocurrent which produces a voltage acros load resistor R. The specimen is scanned by moving it o reciprocating mechanical stage. The changes of light fl resulting from the passage of particles across the field view of the photocell produce pulses of proportionate m nitude which after amplification are fed simultaneously five amplitude discriminators. The discriminators are to a series of predetermined trigger levels, each discrimina giving a standard output pulse whenever the input pu height exceeds its particular trigger level. These standa pulses are recorded by scaling units.

3.1 *Optical arrangement and light source.* The source i tungsten filament coil, 2 mm in diameter and 3 mm long, rated brightness 8×10^{-6} candles/μ^2 (F/53, 6V, 48W p jection bulb). Above it is a lamp condenser which consi of a lens used either alone or in combination with one

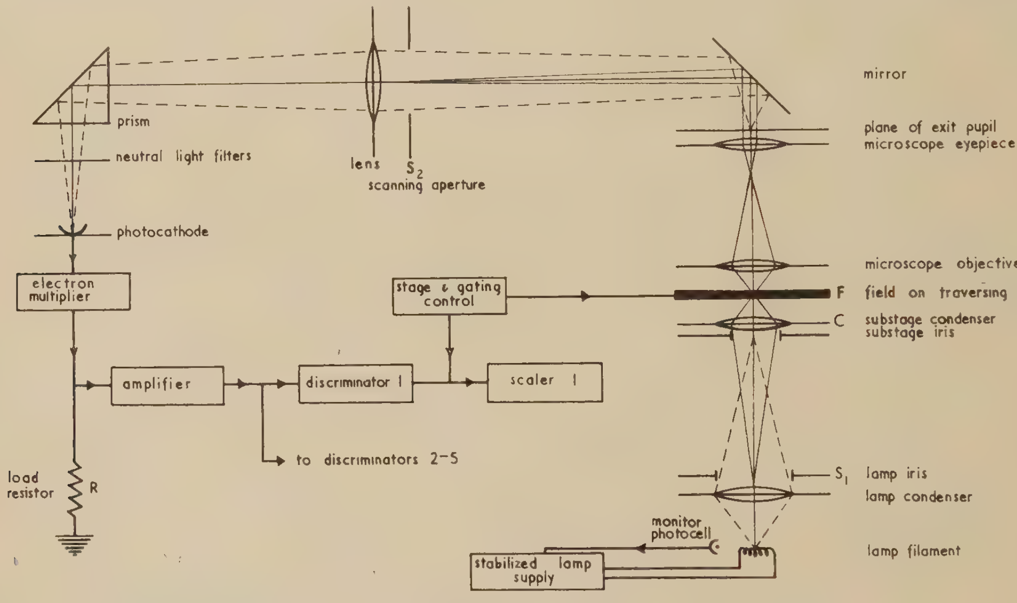

Fig. 4. Arrangement of scanning instrument

two other lenses mounted in a turret: three sizes of filam image, 4·5, 9 and 18 mm long, are thereby available at t first focal plane of the microscope condenser. A small f prevents a column of warm air from forming above the lam A standard objective and eyepiece are used at a mechanic tube length of about 160 mm and an image of the field projected *via* a front-surface mirror on to the scanning sl the distance of projection being 250 mm. Located betwe the scanning slit and the photocell are a lens, a prism f bending the beam and a 10-position turret which contai neutral light filters of various densities. The lens, whic serves to form an image of the exit pupil of the objective the photocell cathode, is necessary because of possible no uniformity in sensitivity of the cathode.

The length of the scanning slit, i.e. the width of the trac is defined by a pair of jaws the separation of which is adjus able from 0 to 10 mm by a micrometer screw. A simil pair of jaws at right angles to the first and 4 mm in front them defines the slit breadth. The slit opens symmetrical about the optical axis of the system. Visual focusing of t field is carried out on the projected image at the fro surface of the slit. For measurement of the magnification the optical system the slit is removed and replaced by a

raved screen (5 cm divided in millimetres) in the plane
way between the two pairs of jaws.

he power source of the lamp is a special stabilizing unit
ch consists of an oscillator and driver stage followed by
amplifier giving the necessary output of 48 W at 6 V; the
llator operates at 2 kc/s giving a ripple-free output. The
t source is monitored by a photocell the output of which
sed to oppose changes in light flux.

2 *Reciprocating mechanical stage.* The stage, which is
the compensated leaf spring type, is reciprocated by a
tor-driven cam to give a traverse 12·5 mm long. A screw
ad gives the stage a continuous lateral displacement so
t successive traverses are 50 μ apart. To guard against
rious counting at reversal of the stage a photoelectric
em is used to render the scaling units inoperative at the
s of each traverse, leaving an effective track length of
nm. The average speed of the stage over this central
tion is 64 mm/s (16 μs/μ). The traverses are counted
tromagnetically and when 100 have been made the stage
utomatically reversed and returned to its starting point,
nting being continued. The length of track scanned is,
refore, 200 cm contained in an area 10 × 5 mm. The
l time taken is 1 min. For some applications, e.g. the
nting of thermal precipitator samples, other track lengths
e been used. The stage can be manipulated manually by
micrometer screws.

.3 *Photomultiplier, amplifier and discriminator circuits.*
photomultiplier cathode follower, the amplifier and the
riminator are directly coupled. A 6094 photomultiplier
Electrical and Musical Industries Ltd.) is used, its gain
ng controlled by varying the potential of the seventh
ode by means of a potentiometer known as the light level
trol. Negative going pulses are passed from the photo-
ltiplier to the amplifier via a cathode follower in the input
which there is a second potentiometer, the dark level control.
amplifier, the output of which is indicated by a meter
n scale, 0 to 10 mA), has a gain of 100, giving an output
ng of 100 V for a voltage change across the load resistor
of 1 V. A convenient value for *R* is 250 kΩ so that a
rent of about 4 μA is drawn from the photomultiplier.

he light and dark level controls are used to set the range
amplitudes of the signal pulses, the former being used to
the amplifier output to a fixed value (9·4 mA, zero signal)
en the scanning slit is unobscured and full light is falling
the photocathode and the latter being used to set the
put to a second fixed value (2·8 mA, 100% signal) when
slit is completely covered by a particle. The operation
the light and dark level controls is not independent and
y are adjusted alternately until both are correctly set.

he amplifier output is coupled to five Schmitt discriminator
cuits each of which is provided with a graduated bias
trol (10 in. scale having 100 divisions). The state of each
criminator is shown by a cathode-ray tuning indicator
ich is employed in setting the trigger point of the dis-
minator to correspond to any fractional signal ($p = z/w$)
indicated by the output meter. Each discriminator circuit
an hysteresis voltage of 6 V: this is the amount by which
input voltage to it must drop below the trigger point
ore the circuit returns to its initial state and can accept a
sequent signal. Positive going pulses from each dis-
minator are amplified and taken to the scaler inputs.

CHARACTERISTICS OF SCANNING INSTRUMENT

he overall stability of the instrument including the light
it is such that a mains change of ±20 V results in a change of less than a ±0·05 mA (1% of maximum signal) at the output meter. Three characteristics of the circuits are of importance. They are (1) the preservation of the amplitude relationships of signal pulses, (2) the resolution of signal pulses and (3) the noise voltage relative to that of the signal pulses. These characteristics are dependent on the load resistor *R* and on the illumination. The limits they set to the minimum particle size that can be assessed depends on the scanning speed employed.

The procedure adopted for adjusting and assessing the electronic circuits was as follows. The amplifier was first set for minimum distortion, judged by visual inspection of the output waveform, of rectangular pulses (0·1 μs rise time) injected at its input. It was then more precisely adjusted by setting it to give constant amplification, assessed by measurement of input and output r.m.s. voltages, of different frequencies of sine-wave inputs. The optimum response that was attainable is flat to within ±2·5% up to 50 kc/s and is 30% attenuated at 90 kc/s. Next the response of the whole system to pulses was investigated by means of a neon bulb placed before the scanning slit and pulsed by a rectangular voltage to give negative light pulses: the output of the photomultiplier showed these light pulses also to be rectangular over the range of pulse durations used. With a load resistor *R* of 250 kΩ the signal pulses reached their full amplitudes throughout the system for pulse durations down to 6 μs. The instrument resolves and counts 10 μs pulses correctly up to a frequency of 40 kc/s: for longer pulses the maximum resolving rate is of course lower.

For a scanning speed of 64 mm/s (16 μs/μ) these data mean that the circuits can preserve the full height of rectangular pulses 0·4 μ long and can resolve these pulses provided they occur at intervals exceeding 1·6 μ. Particles of diameter x when scanned by a slit give pulses approximating to a sinusoidal shape, the rise time of a pulse being equivalent to a stage movement of $x/2$. One can expect such pulses to be correctly amplified for particle sizes down to 0·8 μ.

The noise voltage and hence the minimum size of scanning aperture that is available depend on the characteristics of the individual photomultiplier cell used. The photocell in all the tests described in this paper has a cathode sensitivity of 50 μA/lm and a dark current of 0·008 μA (manufacturer's ratings): it was operated at 850 V.

An investigation was made, using objectives of different numerical aperture (*N.A.*), of the minimum scanning aperture for which the instrument could be set up to count completely opaque particles. It was found that this minimum area could be expressed approximately as $0{\cdot}2/(N.A.)^2\ \mu^2$. If a minimum aspect ratio (length: breadth) of 5 : 1 is permitted for the slit, the minimum length of scanning slit available is $1/N.A.\ \mu$. The gain (light level control) has a range of 20 to 1 and therefore needs to be at minimum for a slit $20/N.A.\ \mu$ in length. If longer scanning slits are necessary, a reduction in signal is produced by reducing the intensity of the illuminating beam by means of neutral filters.

The signal pulses are modified by the random noise fluctuations present in the circuits. If the peak-to-peak (positive-to-negative) amplitude of noise at the input to the discriminators exceeds the hysteresis voltage (6 V) of the discriminator circuits, multiple counts of a signal pulse are possible. The other possible effect of noise is a spurious increase in height of a signal pulse by an amount up to half the peak-to-peak noise voltage. For the present purpose the maximum noise voltage has been taken to be the amplitude that is not exceeded by a noise pulse more often than once per second; since the instrument is capable of resolving more than 20 000 noise pulses per second this pulse height is a rarely occurring one. The probability of at least one such maximum pulse occurring during the passage across the slit of a 10 μ particle is of the order of 2×10^{-4}.

In this section all noise amplitudes are expressed as percentages of the maximum signal voltage, i.e. of the voltage change generated when a particle completely obscures the light passing through the slit. At maximum gain (minimum area of scanning aperture) the peak-to-peak noise present on the unobscured light level is 27% and, at minimum gain (scanning aperture 20 times as large) it has fallen to 9%. The noise voltages present on signal pulses are smaller than these values at the full light level. For instance, on a 50% signal pulse the noise voltages are 19% and 6%, respectively, at maximum and minimum gain, and on a signal resulting from a full obscuration of the slit are 7% and 2%. A somewhat different situation in regard to noise arises when the signal pulses are produced not by opaque particles but by transparent images in an opaque film. In this latter case it is the largest, and in general therefore the longest, signals which have superimposed on them the largest noise amplitudes.

5. PERFORMANCE OF SCANNING INSTRUMENT

Data are here presented on comparative instrument-visual sizings of four fractions of coal particles of sizes in the range 1·5 to 50 μ, of a fraction of alumina particles of sizes 5 to 20 μ of transparent images of these alumina particles formed in an opaque metal film and of counts of particles 1 to 5 μ in thermal precipitator samples of coal. Results are given on the reproducibility of instrument sizings for one of the coal fractions and for thermal precipitator samples; the contribution to the random error of some factors is estimated. An indication is given of the time taken to carry out a sizing with the instrument.

5.1 *Experimental procedure.* Areas of coal particles suitable for sizing were prepared by dispersing a sufficient quantity of powder in acetone which was afterwards thickened with a roughly equal quantity of Durofix. A drop of the suspension so prepared was spread into a thin film over a microscope slide, when it rapidly dried to give an optically clear film containing the particles. A cover slip was cemented on to the specimen with a microscopical mountant. A different technique was used for alumina particles because it was desired to have the particles mounted in air both for direct sizing and for preparation of transparent profiles of them. With alumina then, the powder was dispersed in methyl alcohol and a few drops of the suspension allowed to run down a microscope slide supported at a slight angle to the horizontal. The alcohol was evaporated off quickly by heating the slide, leaving a well-dispersed area of particles. For direct sizing, the specimen was protected by a cover slip cemented at the edges only. Transparent profiles of alumina particles in an opaque film were prepared using the vacuum evaporation method described by Hamilton and Phelps.(9) Aluminium was evaporated on to a particle-covered slide perpendicularly to its surface at a pressure sufficiently low for the shadows of the particles to be sharp. The particles were subsequently washed off leaving transparent profiles which were protected by cementing on a cover slip. If it is necessary for the profiles to be accurate replicas of the projected areas the evaporating source must be substantially a point one at infinite distance, but this was not essential for the present tests. During evaporation part of the slide was shielded to maintain a transparent area necessary for setting of the instrument light level. The metal coating was not made completely opaque since the specimens were to sized visually on a bench microscope.

Because of possible non-uniformity of particle conc tration over the area under a cover slip it is necessary making comparative counts that substantially the sa 10 × 5 mm area of the field be sampled in all sizings o specimen. On each slide, therefore, a distinctive field particles was found near the centre of the cover slip and drawing of this field made. All sizings of the specimen w then made in a 10 × 5 mm area centred on the chosen fiel

Although the instrument assesses particles by their ma mum chords in a fixed direction it was not thought practi to attempt a visual assessment of these. Instead vis sizings were, with one exception, made according to Fere diameter which while larger than the maximum chord is similar, one-dimensional property as opposed to the tw dimensional projected area. Both the instrument and vis sizings were of particle diameters parallel to the length of t slide. For the smallest fraction of coal particles, becau of the smallness of the images, the visual sizing had, unf tunately to be in terms of the projected area diameter. T visual sizings were made in white light on a monocular ben microscope with the aid of a May (Porton)(10) gratic mounted in a ×25 compensating eyepiece.

For sizing by the instrument each specimen was mou on the stage, positioned and levelled. If, because of no flatness of the microscope slide, the particle images at t slit did not appear to stay substantially in focus over t whole of the sample area the slide was rejected. A furth check made was of variations in the light transmitted by t different areas of the slide; if the light intensity varied ov the sample area by more than ±2% the specimen was n used. Focusing for an instrument sizing was always carri out by finding the setting of the microscope which gave maximum pulse count when the specimen was scanned a slit of representative length. Although the setting agre quite well with that for visual focus, there were indicatio that it is up to 1 μ higher.

In making an instrument sizing it is necessary, in order t define the 100% signal level, to set the amplifier output to standard value (2·8 mA) with the slit completely covered by particle. (The longest slits required are larger than t largest particle present and have to be obscured for th purpose not with a particle but with a light filter of equ density.) With coal this setting of the dark level presents difficulty, but with a non-uniformly opaque material such alumina the particle density to assume is by no means obviou The theoretical treatment(3) for uniformly opaque mater shows that if the fractional discriminating level p is set to and the sizing level z is below the size of the smallest parti present, then the pulse count is independent of the tra width w. The procedure followed for alumina was to fi the density of filter which, used for setting the dark lev gave a count independent of the track width under t required conditions. This method gives for coal an estim of the opacity agreeing well with that obtained by dir measurement, but its adoption as the criterion of t "effective opacity" of a non-uniformly opaque material somewhat arbitrary. For the transparent profiles the da level was set directly on the metal film and the light level the large clear area of slide.

The values of sizing level z chosen for instrument sizin were the same as those corresponding to the size class lim in the visual sizings; these formed a $\sqrt{2}$ series based 53·00 μ. Various sets of values in the range 0·8 to 0· were chosen for the fractional discriminating levels p, ea

Table 2. *Size distribution and concentrations of particles used in comparative tests*

Fraction	*Size(μ)*	*Coal* 1	*Coal* 2	*Coal* 3	*Coal* 4	*Alumina*	*Transparent profiles*
			Number percent of particles oversize				
versize distribution (based on visual sizing)	53	1					
	37	7					
	27	32	2				
	19	74	12			2	2
	13	95	48	1		13	20
	9·4	100	85	4		58	62
	6·6		98	23		95	96
	4·7		100	58	2	100	100
	3·3			91	20		
	2·3			100	65		
	1·7				94		
	1·2				100		
ange of concentrations on slides (no./mm^2)		25–60	110–230	220–270	250–400	30·60	30–60
ange of area concentrations on slides		1–3%	2–4%	0·5–0·7%	0·2–0·3%	0·7–1·4%	0·7–1·4%

Table 3. *Comparison of instrument and visual sizings*

						Mean of values from five slides		
Material	*Sizing*	*Particle diameter assessed*	*Objective (N.A.)*	*Percentage obscuration of light taken as representing full coverage of scanning slit by particle*	*Size taken to represent 100% in calculation of oversize distribution (μ)* z_{100}	*Median size of distribution (μ)* z_{50}	*Geometrical standard deviation of distribution* $s_g = \sqrt{(z_{16}/z_{84})}$	*Difference in instrument and visual estimates of particle concentration oversize* z_{100} *(Per cent of visual estimate)*
Coal action 1)	Visual-observer A	Perimeter	8 mm apochromat (0·4)	—	9·4	23·0	1·39	—
	Visual-observer B	Perimeter	8 mm apochromat (0·4)	—	9·4	24·4	1·39	(−0·6)*
	Instrument	Longest chord	16 mm apochromat (0·2)	100	9·4	26·0	1·42	+13
Coal action 2)	Visual-observer A	Perimeter	4 mm apochromat (0·6)	—	4·7	13·0	1·35	—
	Instrument	Longest chord	8 mm apochromat (0·4)	100	4·7	13·7	1·37	+ 3
	Instrument	Longest chord	3·75 mm fluorite (oil immersion) (0·6)	100	4·7	13·7	1·34	− 5
Coal action 3)	Visual-observer A	Perimeter	2 mm apochromat (oil immersion) (0·9)	—	2·3	5·0	1·41	—
	Instrument	Longest chord	4 mm apochromat (0·7)	90	2·3	5·0	1·42	+10
	Instrument	Longest chord	3·75 mm fluorite (oil immersion) (0·7)	90	2·3	5·2	1·41	+ 6
Coal action 4)	Visual-observer A	Projected area	2 mm apochromat (oil immersion) (0·9)	—	1·2	2·6	1·32	—
	Instrument	Longest chord	2 mm apochromat (oil immersion) (0·9)	90	1·2	2·7	1·38	+ 4
mina	Visual-observer A	Perimeter	4 mm apochromat (0·6)	—	4·7	9·9	1·30	—
	Instrument	Longest chord	8 mm apochromat (0·4)	73	4·7	11·8	1·20	+ 2
nsparent profiles	Visual-observer B	Perimeter	4 mm apochromat (0·6)	—	4·7	10·8	1·28	—
	Instrument	Longest chord	8 mm apochromat (0·4)	Set on specimen as described in text	4·7	10·1	1·32	− 2

* Difference between visual estimates.

set forming a $\sqrt{2}$ series. The results were evaluated graphically, a typical plot being shown in Fig. 3 and the derived distribution in Table 1.

5.2 *Comparison of instrument and visual sizings.* Data on the size distributions of the fractions together with the range of particle concentrations on the slides used are given in Table 2. In Table 3 are summarized the results of the sizings. For each comparison five slides were used.

Each fraction had been so prepared as to have a fairly well defined lower limit of particle size. The size class limit in the standard series nearest to this smallest particle size has been taken as representing it and is referred to as z_{100}. The size distributions are all approximately log-normal and have been characterized by (1) the median size z_{50} of the particles oversize z_{100} and (2) the geometric standard deviation s_g of sizes, computed as being $(z_{16}/z_{84})^{1/2}$. All comparisons are in terms of the distribution of particles by number.

Since there are not many particles present of sizes near to z_{100}, errors of sizing can be expected to have comparatively little effect on the estimate of concentration over this size. The differences between the instrument and visual estimates of the concentration of particles oversize z_{100} are shown in the last column of Table 3; these differences can be attributed to "counting" rather than "sizing" errors.

5.3 *Reproducibility of instrument sizings.* In order estimate the variation in instrument sizings and the separ contributions to this variation of (1) positioning and levell the specimens on the stage, and (2) setting the instrumen levels, ten slides of coal particles (sample 2, median size 13 were used. The particle concentrations on the ten slides w in the range 10 to 220 particles per square millimetre, i.e. area concentrations were in the range 0·2 to 4%. A siz of each specimen was made in the usual manner and th the slide being left untouched on the stage, the focus of microscope and the instrument light level, dark level a discriminator settings were destroyed. These were reset a a second sizing made. The slide was removed from the sta to be returned at some later date for a further two sizings be made. Between the two sets of sizings the alinement the optical system was disturbed and reset.

The variations in terms both of concentration oversize a of number per cent oversize are shown in Table 4. Only 9·4 μ is the "between placings" variation in concentrati significant (at the 5% level) compared with the "rep sizings" variation, although at two further sizes 13·2 a 18·8 μ it approaches significance. Over most of the s range the coefficient of variation of the oversize conce tration is about 10% Expression of the results in terms

Table 4. *Reproducibility of instrument sizings of coal particles*

				Standard deviation of	
Size (μ)	*Mean percentage oversize by number*	*Source of variation*	*Degrees of freedom*	*Concentration oversize—expressed as percentage of that concentration*	*Percentage oversize—expressed as percentage of total oversize 4·7 μ*
4·7	100	Between slides	9		—
		Between placings	10	—	—
		Repeat sizings	20	—	
		Total within slide		9·8%	
6·6	97·4	Between slides	9		—
		Between placings	10	—	—
		Repeat sizings	20	—	4·3%
		Total within slide		8·4%	4·3%
9·4	90·8	Between slides	9		—
		Between placings	10	7·3%*	—
		Repeat sizings	20	5·3%	5·8%
		Total within slide		9·0%	5·8%
13·2	55·4	Between slides	9		—
		Between placings	10	—	—
		Repeat sizings	20	—	6·2%
		Total within slide		10·6%	6·2%
18·8	14·1	Between slides	9		4·7%†
		Between placings	10	—	—
		Repeat sizings	20	—	1·6%
		Total within slide		13·5%	1·6%
26·5	1·9	Between slides	9		1·4%*
		Between placings	10	—	0·2%‡
		Repeat sizings	20	—	0·2%
		Total within slide		26·2%	0·3%

* Indicates significance at 0·1% level. † At 1% level. ‡ At 5% level.

oversize distribution enables a comparison to be made veen slides. At 18·8 μ and at 26·5 μ there is a significant tween slides" variation which could not be correlated the particle concentrations on the slides. Further, at 5 μ the "between placings" variation is also significant. r most of the distribution the standard deviation of the aber per cent oversize is about 5% of the total over 4·7 μ. nvestigation has been made of the precision with which the c and light levels and the fractional discriminating level be set. To do this a field of coal particles was scanned a slit of length 33 μ and a sizing level of 13·2 μ, a value to the median size of the particle distribution. Under e conditions the pulse count changed by 10% for a 1% nge in fractional discriminating level so that variations in level were easily detectable. It was found that (1) the eat error arising from short term (2 min) instability of the uits and from inaccuracies in retracing the scanning path tributed to the sizing level a coefficient of variation of %, (2) setting the light and dark levels contributed 0·5%, (3) setting a discriminator and the inhomogeneity veen the five channels contributed 0·8%. The total dom error in sizing level arising from these sources is efore 1%.

nder these scanning conditions, the *N.A.* being 0·4, a displacement of the microscope resulted in only a 1·5% nge in pulse count. At the larger numerical apertures essary when sizing smaller particles, and when the particle knesses are themselves less, focusing is more critical. h a thermal precipitator sample of coal particles, for mple, the *N.A.* being 0·9 and the sizing level 1 μ, a 1 μ placement of the microscope produced a 10% change in se count.

.4 *Time taken for an instrument sizing.* With a five-nnel instrument, the establishing of an oversize distri-ion at *n* sizes forming a $\sqrt{2}$ progression requires $n + 3$ cessive scans with slits of different lengths if four counts to be available for establishing the concentration over n size. Each scan lasts a minute and between each scan counts have to be recorded and the instrument reset. instrument is occupied in addition for the time necessary its initial setting up and for the levelling of the specimen the stage. The total time taken is 30 to 45 min depending the spread of the distribution. The ancillary operations preparation of the specimen and evaluation of the results st also be included in the time of sizing, but it is possible them to be performed by another person and for the rument thereby to be kept in continuous operation.

he sample area in an instrument sizing varies from some m^2 at 1 μ to 50 mm^2 at 25 μ and above.

.5 *Counting of thermal precipitator samples.* For counting the instrument the cover slip carrying the sample needs be mounted on the slide without distortion; those used e all wax-mounted, it having been found that this produced curvature of the slip than did paper-mounting.

n Table 5 are shown comparative instrument-visual counts hermal precipitator samples of a laboratory cloud of coal t. (The samples were supplied by the Safety in Mines earch Establishment.) The first series of instrument nts were made over the standard instrument area of × 5 mm, but as there were obviously considerable numbers particles outside the thermal strips the area was later uced to 10 × 2 mm to conform with standard visual ctice. The mean count was thereby reduced by 11%. the instrument sizings, each estimate of particle concen-ion oversize was derived from counts at two slit lengths y. The values shown in Table 5 are means of two sizings for the 10 mm × 5 mm results and of four sizings for the 10 × 2 mm results. The samples in addition to being counted visually (by circle comparison) in the British Coal Utilisation Research Association (B.C.U.R.A.) laboratories were counted also in the Northern (N. and C.) Division of the National Coal Board (N.C.B.). The 10 × 2 mm instrument counts are, on average, 1% higher than the N.C.B. visual counts and 20% lower than the B.C.U.R.A. ones.

Table 5. *Comparison of instrument and visual counts of thermal precipitator samples of coal dust*

	Total number of 1 to 5 μ particles on cover slip			
Slide number	*Instrument 2 mm objective (0·9) area 10 × 5 mm set to opacity 90%*	*Instrument 4 mm objective (0·7) area 10 × 2 mm set to opacity 90%*	*Visual observer A*	*Visual (N.C.B.)*
1	20 800	20 600	31 800	17 200
2*	24 800	—	19 500	—
3	12 200	10 600	13 700	12 000
4	12 100	11 300	12 200	9 000
5*	6 800	—	8 800	—
6	19 400	15 500	21 700	16 400
7	16 000	15 700	18 300	13 300
8	11 200	9 200	10 400	10 100
9	10 800	8 000	10 400	9000
10	3 800	4 800	6 000	5 300

* These specimens were ruined by seepage of immersion oil under the cover slips.

Thirteen thermal precipitator samples of mine dust (supplied by the Northern (N. and C.) Division of the N.C.B.) showed poorer agreement between counts, the instrument ones being an average of 30% lower than N.C.B. visual counts. These samples contained a considerable proportion of transparent rock dust particles and this proportion varied from sample to sample.

Each of the thirteen mine dust samples was placed twice on the stage of the instrument and at each placing was sized twice. An analysis of variance carried out on the results showed the "between placings" mean square to be significant at the 5% level for the count of particles oversize 1 μ, to be significant at the 1% level for the count oversize 5 μ and to be significant at the 5% level for the resultant 1 to 5 μ count. The various coefficients of variation are shown in Table 6.

Table 6. *Reproducibility of instrument sizings of 13 thermal precipitator samples of mine dust*

	Coefficient of variation of estimate of number of particles in size range contributed by		
Size range (μ)	*Placing*	*Sizing*	*Total*
>5	6·5%	7·7%	10·1%
>1	5·1%	4·5%	6·8%
5–1	6·3%	6·9%	9·3%

A record was kept of the time taken for these counts of mine dust samples. The first sizing at each placing took an average of 24 min and the second 6 min. The minimum times recorded were 13 min and 5 min, respectively. For each sizing the actual total time of scanning was only 1¾ min. The difference in time taken between the first and second sizings represents the time needed with the present procedure to position and level the sample on the stage.

6. DISCUSSION

The method used to investigate the accuracy of the instrument can establish it only to 5% or so. Firstly, the visual sizings are not reliable to a greater accuracy than this—as can be seen from the sizings of the largest coal fraction by two observers. Secondly, in addition to the geometrical diameters assessed by the two methods being different it is likely that the eye and photocell locate the "edge" of an optical image by quite different criteria. Lastly, there is, even for coal, a variation of a few per cent between the optical densities of different particles.

The results for coal particles show a systematic oversizing by the instrument under test relative to the visual observer. For particles under 20 μ the difference in size estimation appears to be about 5%, but it is some 15% for the fraction of median size 26 μ. For the transparent profiles in an opaque film the difference in size estimation is of the same order of magnitude as that for coal particles of the same size, but of the opposite sign, i.e. the instrument is undersizing. The various differences may arise from the response of the photocell to the energy distribution in the particle image, which distribution may extend considerably outside the "geometrical" boundaries of the image. For alumina particles of sizes 20 to 5 μ the discrepancy between the instrument and visual judgment of size is 20%, which is larger than for coal and transparent profiles. It is reasonable to suppose that the changed behaviour arises from the uneven optical density of alumina and it appears that the method adopted for assessing the "effective" opacity underestimates it. Use of the metal shadowing technique clearly enables a more reliable instrument sizing of such material to be made. The instrument estimate of spread of the size distribution agrees well in almost all cases with the visual: the similarity of this spread for the different fractions is fortuitous and has arisen only because the fractions were all prepared in approximately the same way. There are differences of up to 15% between the instrument and visual estimates of total particle concentration. These are not accounted for by the instrument-visual differences in size estimation and no satisfactory explanation of them has been found.

For all the instrument sizings the objective used on the instrument was that which would normally be used for sizing in that range whether by the instrument or visually by the standard method of circle comparison. For the smallest coal fraction, where the quality of the optical system was likely to be critical, the same objective at the same *N.A.* was used for both the instrument and the visual sizings. For the other fractions, however, a higher power objective was used for the visual sizings than for the instrument ones in order to enable a more reliable assessment of Feret's diameter to be made. For coal fraction 2, use of higher *N.A.* oil-immersion objective reduced by 4% the instrument estimate of the concentration but did not change the estimate of the median size. For coal fraction 3, changing to an oil-immersion objective of equal *N.A.* reduced the estimate of concentration but increased the estimate of size, each by 4%.

The method adopted for relocating the area of the specimen sampled in the comparative sizings would appear to be an adequate one for particles under 25 μ in size since (see Table 4) over most of a size distribution there was no significant variation between placings of a slide on the stage. Neither did there appear to be any significant difference between similarly placed 50 mm^2 sample areas on different slides except at sizes at which there was less than 20% by number of particles oversize.

At the median size (13 μ) of the fraction used in the reproducibility investigation the observed standard deviation of repeated sizings of the same field amounted to 10·6% of the concentration oversize 13 μ. This variation is equivalent to a standard deviation in the sizing level of 0·4 μ, i.e. of c 3%. The setting of the discriminating level of the electro circuits contributes a coefficient of variation of only 1% each of the pulse counts. Since, however, these pulse cou have to be differenced in order to derive a particle conc tration, the resultant error in the count may be considera larger if the difference is a small one. Also contributing the 3% error in sizing level is lack of precision in focusing

The times taken for instrument sizings indicate that so 5 to 10 sizings a day could be carried out by an opera working alone: in comparison, a visual observer can ca out about 2 determinations each day. The instrume therefore, while quicker, is only several times so.

The thermal precipitator counts indicate that the inst ment can assess with tolerable accuracy samples of a hom geneous, opaque material such as coal, the count 1 to having a coefficient of variation of about 10%. In the t described, the time taken (24 min) was prohibitive, larg because of the long time spent in levelling the specimen the stage.

7. CONCLUSIONS

The instrument has been shown to produce estimates the concentration and size distribution of graded fracti of coal particles in the size range 2 to 50 μ which are in s stantial agreement with visual measurements. There however, a tendency for the instrument to assess sizes being 5 to 15% larger than the perimeter diameter as s by a visual observer. The reasons for the discrepancy not understood. Similarly, the instrument satisfacto assesses transparent shadow profiles of particles. The p formance on variable opacity material is not so go although even in this case the results are on average wit 20% of the visual ones.

Although data have not been presented on sizings particles smaller than 1·5 μ the electronic circuits respond satisfactorily to the pulses from such smaller partic If necessary, the stage speed could be reduced below tha present use and this would bring the lower limit of size by the electronic circuits well below that set by optical c siderations. The main practical difficulty in sizing be about 3 μ is ensuring that the particle field over the whole the sample area is flat to within the depth of focus of a to 1·3 *N.A.* objective. The microscope slides have to selected carefully and a slide-levelling device to fit to stage would be of great value. The sample area of 50 m is unnecessarily large for particle sizes below 3 μ and reduct of it (which is easily effected) would ease the problem flatness. Use of oil immersion has not presented any d culties and does in fact improve the conditions of scannin

For the application of the instrument to sizes of parti larger than 50 μ the 50 mm^2 sample area is undesirably sm Construction of an alternative larger stage giving, say 100 cm^2 sample area would usefully extend the range of instrument. It should also prove possible to size sp droplet images and electron micrographs on such a stage.

No satisfactory correction for errors due to coincidence particles in the scanning slit has been arrived at. In the t described the problem was avoided as far as possible keeping the particle concentration low. An area conc tration of 4% (equivalent to a mean particle spacing 5 diameters) is probably the highest that it is safe to use a one of 1 to 2% is preferable.

The production of transparent shadow profiles as an in mediate process offers a method whereby the instrument be used to size material containing particles of a wide ra ptical densities. If the range of opacities is not great or e opacity varies within a single particle, the results for ina suggest that instrument sizings can be made directly: e would be sufficiently accurate for much routine work, process control, but it might be necessary to calibrate nstrument by reference to a visual sizing or to an instru- t sizing of shadow profiles of the material.

he instrument is less flexible than a visual observer in the of area that is sampled and is therefore less well suited the determination of a weight distribution of material nding over a wide range of sizes. Coincidence errors ld appear to be most serious for the largest sizes of such stribution in which particles representing only 0·01% of number distribution may make up 10% of the weight. ight, however, prove practical to combine a visual sizing he small number of large particles with an instrument g of the many smaller particles. The instrument is more ble than a visual observer in regard to the spacing of ranges. These ranges can be made as wide or as narrow s necessary and this is particularly useful with closely led material when the $\sqrt{2}$ size ranges used in visual sizing not permit a sufficiently precise determination of the ibution.

he reproducibility data indicate that the instrument ility and the precision of setting the discriminating level not make the major contribution to the variation in lts and can, therefore, be regarded as adequate. Some he variation might be removed by refinement to the sing procedure and to the experimental procedure rally.

he speed of sizing with the instrument is some 5 times ier than that of a visual observer. The efficiency of use he instrument increases with the particle concentration he field and with the number of size ranges assessed. rating the instrument is much less tiring than making a al sizing.

8. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the various contributions to the development of the instrument made by Mr. R. P. Abraham and Mr. A. E. Fitzsimmons of Casella (Electronics) Ltd., and by Mr. P. G. W. Hawksley and Mr. J. H. Blackett of the British Coal Utilisation Research Association. They wish to thank also Miss W. Manders for carrying out most of the visual sizing and Mr. J. R. Hodkinson of the Safety in Mines Research Establishment and Mr. R. W. C. Wheatley of the Northern (N. and C.) Division of the National Coal Board for their co-operation in regard to the supply and visual counting of thermal precipitator samples.

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Method of measuring displacement using optical gratings

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The paper describes a method of using three diffraction or shadow gratings for accurate linear measurement. Comparison between the gratings produces two alternating signals, and the change of phase difference between the signals is proportional to the distance measured.

eral methods have been devised by which two diffraction shadow gratings are used to form moiré or shadow ges.(1,2,3) When one of the gratings, the reference ting, is fixed and the other, the measurement grating, is ved, the fringe pattern moves. A movement of one line ce of the grating is represented by a movement of the ge pattern of one complete fringe, and if the light intensity a particular point is detected by a photocell and slit, the sage of fringes may be counted. In order to determine direction of motion of the grating, two or more photocells required.

n such systems the measurement of whole fringes presents difficulty, but if it is desired to measure fractions of a fringe accuracy of the relative positioning of a number of photo- ls and the accuracy with which each cell measures light ensity are involved. The limitations on photocell position- are obvious, while temperature drift and non-linearity in photocells reduce their accuracy. The effect of these errors can be reduced at the expense of increasing the amount of equipment required.

An alternative approach, described here, avoids these difficulties. The two gratings in the above scheme are no longer compared directly with each other. Instead each is compared with a third, comparison, grating which moves continuously in one direction. The fringe patterns resulting from these comparisons are detected by two photocells, which give alternating signals even when the measurement grating is stationary. The relative timing or phase of these signals, rather than their amplitude, may be used to perform the desired measurement.

THE THREE-GRATING SYSTEM

The system is illustrated in Fig. 1. The comparison grating is mounted on a drum which rotates at constant speed. An image of part of this grating is formed, *via* the beam-splitting cube, on each of the other two gratings, to produce fringe patterns which are detected by the two phototransistors. The signals from these photocells will be periodic owing to the motion of the drum. If the measurement grating is moved to a new position, the cumulative change in the phase difference between these signals is a measure of the displacement. A phase change of 360° corresponds to a movement of one line space, and the sign of the phase change indicates the direction of movement.

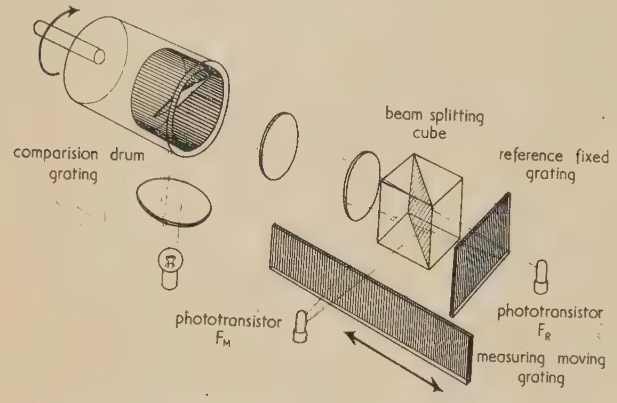

Fig. 1. Schematic diagram of the optical system

Complete cycles of phase change are counted, and the count is displayed on a reversible dekatron counter, the unit being one line space. The residual phase difference, or fraction of a fringe, is measured and displayed on a meter. The reading of the counter and meter at any time gives the displacement of the measurement grating from a datum position.

THE COUNTING OF COMPLETE FRINGES

The photocell signals, F_R formed by the comparison and reference gratings and F_M formed by the comparison and measurement gratings, are approximately sinusoidal. They are squared and differentiated to give a pulse once per cycle (Fig. 2).

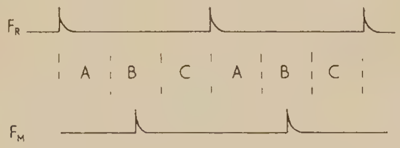

Fig. 2. Waveforms derived from the photocell signals

The signal F_R is of nearly constant frequency and the time interval between successive pulses is almost constant. This interval is divided into three equal parts A, B, C. As the measurement grating moves, the pulses F_M move relative to the pulses F_R and thus occur in turn in the intervals A, B, C, A, B, . . . etc. for one direction of movement, and in the intervals A, C, B, A, C, . . . etc. for movement in the opposite direction. A transition from interval C to interval A causes an addition of one to the counter, while a transition from interval A to interval C is recorded by subtracting one from the counter.

There will be a limitation on the maximum speed of the measurement grating. When the grating is moving slowly, the pulses F_M will occur many times in each of the intervals before moving to the next. As the speed increases the pulse occurs fewer times in each interval until the limiting case, when it occurs only once. If the intervals A, B, C are equal in duration, then the maximum speed of the measurem grating must not exceed one-third of the peripheral speed the drum.

THE EFFECT OF VIBRATION

If the measurement grating is subject to vibration and positioned so that F_M and F_R are exactly in phase, a success of alternate add and subtract pulses may be produc causing the counter to oscillate through one digit. This eff may be overcome by introducing a backlash region x betw A and C, the magnitude of which is slightly greater than maximum vibration amplitude (see Fig. 3). This region then considered to form part of either interval A or according to the direction of movement. When passing fr C to A, for instance, x is considered to form part of inter C and an add count is not generated until A is reached. Wh this happens, x is regarded as part of interval A until C occ

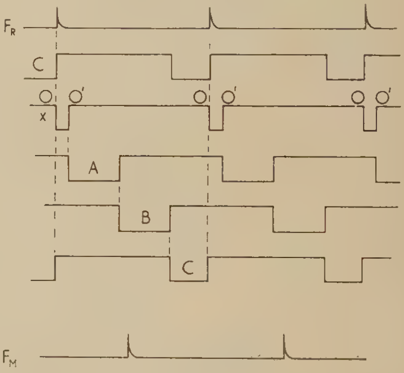

Fig. 3. Idealized waveforms for whole-fringe detecti

again, and oscillations across the x–A dividing line have effect on the counter.

It would be possible to use interval C as a backlash regi However, the extent of the backlash region determines accuracy with which phase can be measured, and since, general, it is desirable to make the backlash as small as vibration amplitude will allow, a separate region is introduc for this purpose.

A logical circuit for producing the counting pulses is sho in Fig. 4. The reference signal F_R is converted to a squ

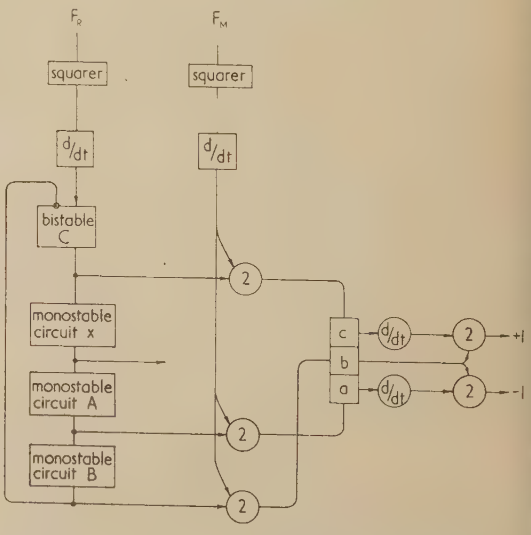

Fig. 4. Logical diagram of whole-fringe detector

e and differentiated and the resulting pulse triggers a able circuit C. The output of the bistable circuit triggers a nostable circuit x which, on recovery, triggers a second nostable circuit A. Circuit A triggers a third circuit B ch resets the bistable circuit. In this way the reference al produces the four signals shown in Fig. 3, which appear he outputs of C, x, A, B respectively. Three of the signals 4 and B are fed to three coincidence gates, the other input ach gate being the pulse F_M. The outputs of these gates connected to a trigger circuit c, a, b which has three stable es, a off, b off, or c off. If any one input is present the ger is set with the corresponding output absent, and with input the trigger remains in the condition set by the last ut. Depending upon the relative phase of F_M and F_R, the se formed from F_M will appear in one of the four intervals x, A or B. If the pulse occurs in interval A, B or C, an put pulse will appear at the appropriate coincidence gate will set the trigger circuit accordingly. If the pulse urs in interval x, there will be no input to the trigger uit which will remain in the state previously set up. For mple, when the pulse from F_M passes from interval A, ough interval x, to interval C, the trigger is first set with ff, it remains in this state while x is traversed, and changes off when interval C is reached. In this way x may be sidered as part of A. Similarly for a change from C, ough x, to A, x is considered as part of interval C. The puts, a and c, of the trigger circuit are differentiated and lied to two coincidence gates, both of which are controlled the output from b. If the measuring signal pulse changes m interval A to interval C, the trigger circuit will change m a off to c off. As c goes off, a will appear, and after erentiation will form a subtract pulse, since b will be sent all the time. Similarly a change from interval C to erval A will generate an add pulse. If, however, a change m interval A to interval B occurs, the trigger will change m a off to b off. As a appears it will be differentiated as ore, but since b is off, no subtract pulse can be produced the coincidence gate output.

THE INTERPOLATION INDICATION

convenient method of measuring the residual phase erence between two signals is to use a bistable circuit, ich is switched in one direction by one signal and back to original state by the other. If the output voltage is zero one state and a maximum in the other, the mean voltage is a asure of the phase difference between the signals. In this e the output voltage is displayed on a meter, the time nstant of which is sufficiently long to smooth out the alter-ing components of the voltage.

f such a scheme is used with the three-interval erence signal of Fig. 2, the zero for phase measure-nt could be the junction of intervals A and C. At s point the meter should indicate either 0 or 360° of ase difference. Since the meter smooths the output the bistable circuit, which at this point will have incident input pulses, and may or may not trigger, false reading is obtained. However, if with the ir-interval system of Fig. 3 the x region is made ual to the smallest interval to be measured, either e of this zone could equally well be used for a ase zero. If one side O is used as the origin when measurement signal pulse is in either interval A or and the other O' is used when in interval C, the false ding when at the origin is avoided with only a all loss of accuracy.

Fig. 5 shows part of the logical diagram of Fig. 4, with the addition of the phase-measuring components. The positive trailing edge of the C signal, which corresponds to O, and the positive trailing edge of the x signal, corresponding to O', are connected to coincidence gates 1 and 2. Gate 1 is also supplied by a signal from c, and gate 2 from a, so that the bistable circuit P is switched on by O when c is present, that is when the measuring signal pulse is in interval A, and by O' when a is present, and the measuring signal pulse is in interval C.

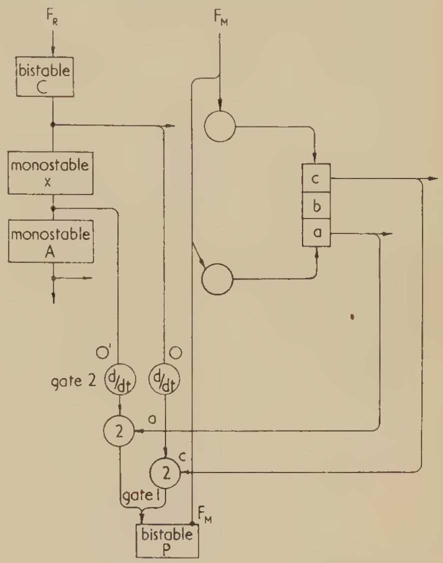

Fig. 5. Logical diagram of part-fringe detector

The measuring signal pulse F_M is used to reset the bistable circuit. In this way, the minimum phase measured by the phasemeter corresponds to the interval x, and the maximum to 360° − x. When an add pulse is produced, the phasemeter changes from its maximum to its minimum indication. The reverse happens for a subtract pulse, and a false reading cannot be obtained.

PRACTICAL CIRCUIT

The bistable circuit and the three monostable circuits may be combined in the circuit shown in Fig. 6. The first transistor is normally cut-off with the other three transistors conducting. A negative input causes J_1 to conduct. The resulting positive-going voltage at the collector of J_1 is applied to the base of J_2, which cuts off and maintains J_1 conducting

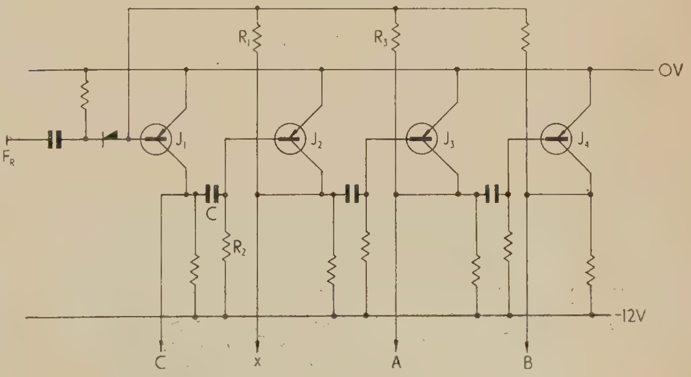

Fig. 6. Circuit diagram of waveform generator

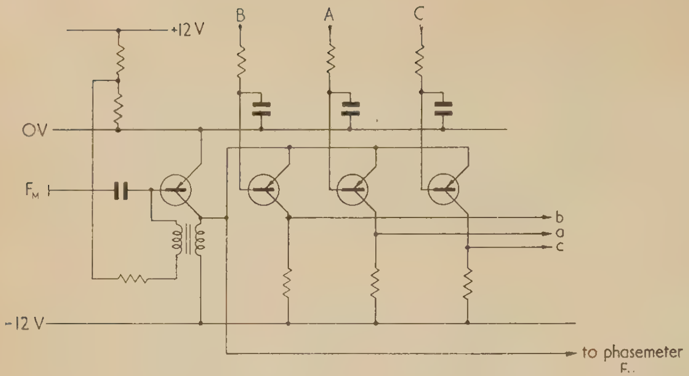

Fig. 7. Circuit diagram of gates

through R_1; after a delay determined by $C R_2$, J_2 becomes conducting. J_3 is then cut-off, maintaining J_1 conducting through R_3. This process continues until finally J_1 is reset. In this way the durations of the x, A and B signals are controlled by CR time constants, while the length of the C signal depends upon the repetition rate of the reference signal.

The output signals from A, B and C are negative going and are applied to the bases of three of the transistors in Fig. 7; the fourth transistor is connected in a blocking oscillator circuit and is triggered from the measurement signal. A short pulse is produced which appears at one end of the three outputs as a positive-going pulse. The three output lines from these gates are connected to the three-stable-state circuit of Fig. 8. In this circuit any two transistors may be conducting and the third cut-off. Any conducting transistor being turned off will cause the non-conducting transistor to turn on.

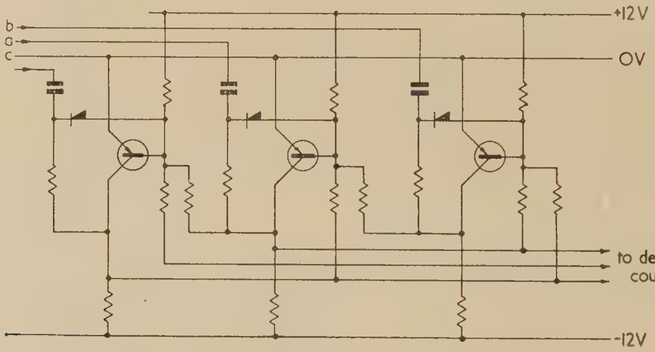

Fig. 8. Three-stable-state trigger circuit

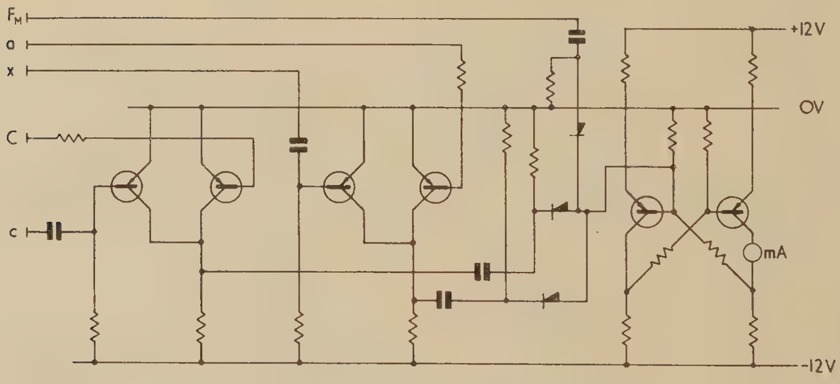

Fig. 9. Part-fringe detection circuit

The signals from the three stages of the three-sta
trigger circuit are connected to a reversible dekatro
counter,(4) which incorporates the differentiating circu
and coincidence gates shown in the output from th
logical diagram.

The circuit for indicating phase shown in Fig.
consists of two coincidence gates each using tw
transistors and a bistable circuit. Since the inp
pulses to the bistable circuit are of opposite sign, th
bistable circuit is triggered on and off on the sam
base.

CONCLUSION

The apparatus described has been constructed in
experimental form using printed screen grating
seventy-five lines per inch, and an interpolation
about one twentieth of a line interval has been obtaine
Careful attention to the mechanical design would mo
certainly enable a finer interpolation to be made.

The authors wish to acknowledge the assistance of
Light Division of the National Physical Laboratory in th
development. The work was carried out as part of th
research program of the National Physical Laboratory and
published by permission of the Director of the Laborator

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Stabilized torque magnetometer

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An improved torque magnetometer has been developed which enables measurements of torque to be made with high precision and under conditions of complete stability.

The specimen torque is balanced by means of an electric current passing through the coil of a moving coil meter movement, which replaces the normal torsion head and wire. A small permanent magnet is mounted on an extended movement pointer, so that one pole is capable of restricted motion in the field of two opposing current carrying coils, which provide the necessary stability.

The principle employed for producing stability is capable of application to fields other than magnetism.

INTRODUCTION

ıen a disk of magnetic material is placed in a uniform gnetic field the sample will rotate to a position of minimum ·rgy, or if restricted in motion, exhibit a torque. The ·que experienced is a function of the angular setting of the k to the field and the relationship between torque and gle gives rise to a torque curve. The existence of a torque lue to the magnetic anisotropy of the magnetic material, uantity which is of importance in magnetism.

The method normally used is to balance the torque of the nple in the magnetic field with a torque due to a torsion 'e suspension or a spring.(1–4) It has been shown by ·bster(5) and Harrison(6) that a stable balance in all positions only possible where the maximum spring or torsion head lexion is below some critical value which is, for example, -sixth to one-third of a radian in simple cubic structures, l depends on the crystallographic plane. Measurements ı only be made in stable positions, which usually means ıt either positions of low torque have poor accuracy, or ·re is a curtailment in the range of torque values that can measured with a given torsion head.

An automatic torque plotter has been reported by ıoyer(7) which utilizes a current carrying coil in a galvanoter-type suspension to balance the specimen torque.

THE INSTRUMENT

In the present instrument (see Fig. 1) the specimen is ounted at the end of a carrier, which is pivoted in jewelled arings and is attached at the upper end to the coil of a oving coil instrument movement. The carrier can rotate ely over a degree or so. To the moving coil, a long counterlanced arm ($\sim$10 cm) is fixed which terminates in a thinged pointer travelling over a mirror with a central fine line. ong the end of the arm a long thin permanent magnet edle is attached firmly so that one magnetic pole can ove between two small solenoids connected in series-position for repulsion.

The meter movement, specimen carrier and coils are all ounted on a circular plate (diameter 12 in.) which can be ated on a ball-bearing movement. Thus the orientation of disk can be changed relative to the magnetic field, which provided by an electromagnet; this magnetic field can be ried up to $H = 4000$ oersteds. A simple pointer, reading to a circular scale on the plate, enables the specimen ting to be measured accurately.

The torque acting on the specimen is balanced by varying current through the moving coil until the pointer and rror line coincide. This current can be measured curately.

It was necessary for a programme of work that stable balance positions should be obtained over the whole range of settings, and to achieve this the stabilizing unit was used.

The current through the two solenoids is adjusted until a stable setting is obtainable for any orientation of the disk and is thereafter kept constant. Accuracy in some positions could be improved by reducing the current below this value, but the limiting accuracy is in setting the rotating table and is about $\frac{1}{4}$°, so that in practice the current is kept constant.

The principle and theory of the method are given below.

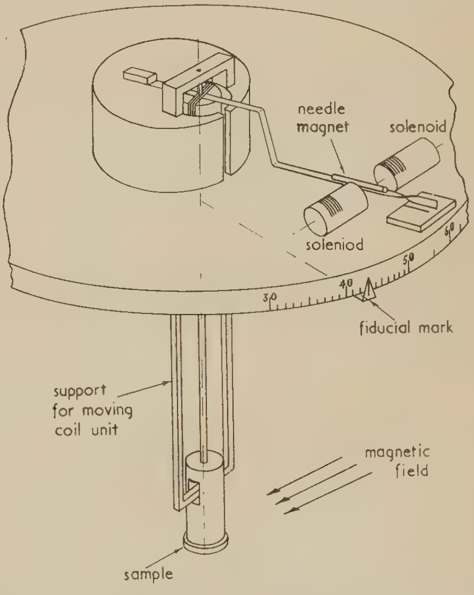

Fig. 1. The general arrangement of the torque magnetometer

CONDITION FOR STABILITY

The condition for stability is that the resultant $d^2E/d\theta^2 > 0$ and $\left(\dfrac{dE}{d\theta}\right) = 0$ (where E is the energy of the system and θ the angular setting), a general result.

Alternatively, the condition can be given as $T = 0$, and $dT/d\theta < 0$, where T is the torque on the specimen. In particular cases where $d^2E/d\theta^2 < 0$, a device is required which exhibits zero restoring force in the central position and has a positive value of $d^2E/d\theta^2$, preferably variable.

In the present magnetometer, the required form of curve has been achieved by using the behaviour of a single magnet pole placed between two opposing long solenoids.

THEORY OF THE STABILIZING UNIT

The theory can be evaluated in terms of energy, or torque, but it is perhaps clearer to use the torque method.

Consider a magnetic pole of strength m_0 situated between the two solenoids of radius R, which are a distance $2d$ apart, and displaced from the centre of the axial line by a small horizontal distance. A current I A flowing through the solenoids produces an effective solenoid of pole strength m (see Fig. 2).

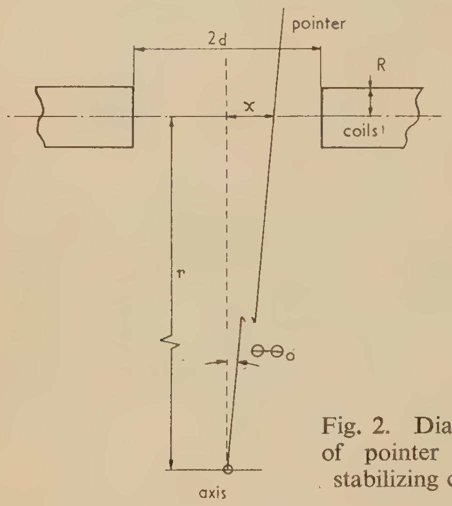

Fig. 2. Diagram of pointer with stabilizing coils

The restoring torque due to the stabilizing unit for displacement off centre can be written as

$$\frac{4mm_0r^2(\theta - \theta_0)d}{(d^2 - x^2)^2} \qquad (1)$$

The torque due to the specimen is $T_s + \frac{dT_s}{d\theta} \cdot (\theta - \theta_0)$ where $dT/d\theta$ is evaluated at $\theta = \theta_0$, and that due to the moving coil movement is a constant value, say $-T_c$.

The resultant torque which is obtained by addition of these three components is

$$T_s + \frac{dT_s}{d\theta} \cdot (\theta - \theta_0) - T_c - \frac{4mm_0r^2(\theta - \theta_0)d}{(d^2 - x^2)^2} \qquad (2)$$

At balance with $\theta = \theta_0$, $T_s = T_c$, and this resultant equals zero.

The balance is stable when

$$\frac{dT_s}{d\theta} \cdot (\theta - \theta_0) - \frac{4mm_0r^2(\theta - \theta_0)d}{(d^2 - x^2)^2} < 0 \qquad (3)$$

The stabilizing unit is only required when $dT_s/d\theta$ is positive, when the necessary condition is that

$$\frac{4mm_0r^2}{d^3} \nless \frac{dT_s}{d\theta} \qquad (4)$$

In terms of energy, equation (4) may be written

$$\frac{4mm_0r^2}{d^3} \nless \left|\frac{d^2E_s}{d\theta^2}\right| \qquad (5)$$

which is equivalent to stating that $d^2E/d\theta^2$ total is positive—the condition for stability in terms of energy.

Equation (1) can be rewritten in terms of the solenoid current using the expression for the field on the axis of a long solenoid (assumed to be of infinite length), so that the condition, on replacing m in the stability equation (5), becomes

$$\frac{4\pi nI}{10l} \cdot \frac{R^2}{(R^2 + d^2)^{3/2}} \cdot r^2m_0 > \left|\frac{d^2E_s}{d\theta^2}\right|_{\theta=\theta_0} \qquad (6)$$

where $\frac{n}{l}$ is the number of turns/cm, R is the radius of the co and I is the magnetizing or stabilizing current in amperes.

The maximum rate of change of torque with angle $\left|\frac{d^2L}{d\theta^2}\right.$ expected for the measurements was 250 dyn cm/deg. and t coils were designed to produce a value about four tim greater than this; they consisted of three layers of 37 s.w. copper wire wound on glass formers 0·6 cm diameter ar 1·5 cm long, whose ends were separated by a distance 0·5 cm. The value of r was 12 cm. From equation (6), can be seen that for optimum field gradient between the coi the end-to-end separation should be $1/\sqrt{2}$ of the coil diamete A small darning needle was used as the magnet and a stabili ing current of about 250 mA was necessary. The moving co instrument parameters were $H = 3000$ oersteds, 40 turns wi 165 mA for a maximum torque of 10 000 dyn cm.

INTERACTION EFFECTS

The torque balance and stabilizing units are both virtual unaffected by the stray field of the electromagnet. T moving coil unit is surrounded almost completely by pe manent magnet material and works in a 3000 oersteds fie and the stabilizing unit is only sensitive to the difference fields at its two poles, which are situated about 25 cm fro the electromagnet gap.

Experimentally, it was found that on switching on t applied field with no specimen present the interaction w small; though sufficient to displace the needle balance so t a coil current of up to 0·2 mA, depending on the need orientation to the magnet field, was required to counte this torque. Such a current can be neglected when compar with the balance current normally used (up to 165 mA).

CONCLUSIONS

A torque magnetometer has been described which enabl magnetic torque curves to be measured accurately by bala ing the specimen torque against that produced by a curr flowing through a moving coil ammeter type of moveme

Stability of the specimen has been achieved in all positio by the use of a stabilizing unit, the principle of which is general application.

The apparatus has been used for a number of investigatio and has proved particularly helpful for an investigation in rotational hysteresis loss in silicon–iron, where the rotation loss is obtained by the area difference between curves obtaine for rotation in a clockwise, and then anti-clockwise, directio

ACKNOWLEDGEMENTS

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Laboratory and workshop notes

cury bleeder valve for critical adjustment of air pressure*

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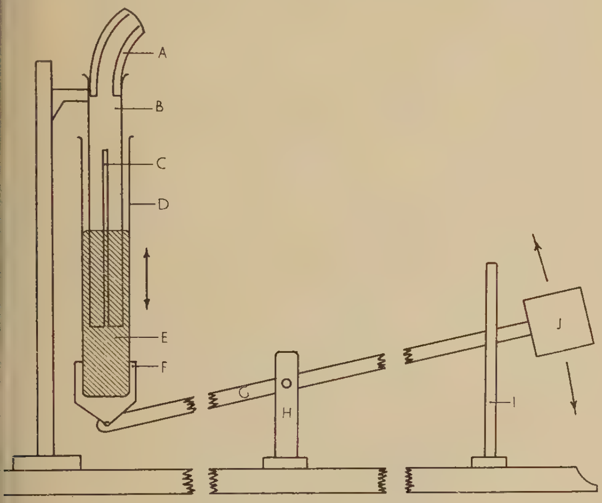
[*Note received* 7 *July*, 1959]

xperiments now under way at this laboratory, it is somes necessary to produce small variations in air pressure pressure-chamber system of approximately nine cubic Variations in pressure as small as a fraction of a ibar are required. An efficient way to provide this degree ontrol was found in using an 18-psi pump delivering air constant rate, in conjunction with a bleeder valve in the sure system which could be very finely controlled and orated for different settings.

he figure is a diagram of the bleeder valve. The valve constructed in a short time from materials on hand. A iglass tube (*B*), 6 × ½ in. with ⅛ in. wall, open at both s, is slit along one side, starting at one end and extending . The slit (*C*) being used at present is just wide enough admit the edge of a piece of ordinary writing paper. end of the tube opposite the slit is fixed vertically to a nd as indicated in the figure. A 6 in. test tube (*D*) is cured with an inner diameter of 1¼ in. A fixture (*F*) is d over the bottom of tube (*D*) and hinged to the end of ver arm (*G*). The lever is held by a fulcrum (*H*) approxitely 6 in. from the tube and extends through a slotted de (*I*). A counter-weight (*J*) is fastened to the free end he lever arm.



Mercury bleeder valve

he tube (*D*) is filled with mercury (*E*) to approximately -thirds capacity and the plexiglass tube (*B*) is inserted into rior to bolting to the upright support. The slit portion the tube is thereby immersed in mercury. When the aratus is assembled, the mercury tube (*D*) can be raised lowered with respect to the tube (*B*) by depressing or ing the lever arm. The weight on the end of the lever ufficiently large to balance the mercury. A numerical e may be fastened to the upright guide (*I*). A length of ber hose (*A*) is fastened to the top of tube (*B*) and leads he pressure system.

y raising or lowering the mercury tube with respect to the slit tube, the effective length of the slit is changed and hence the degree that the system is open to atmospheric pressure. The sensitivity of the valve may be changed by wedging open the slit at the open end of the tube, or by using slits of different widths. The range of pressure variation may be changed by increasing or decreasing the slit length. The present valve is adjusted to give a maximum range of change in pressure of approximately one millibar with the mean experimental-chamber pressure near atmospheric. In this valve, the guide (*I*) is adjusted to provide sufficient friction to maintain any lever setting.

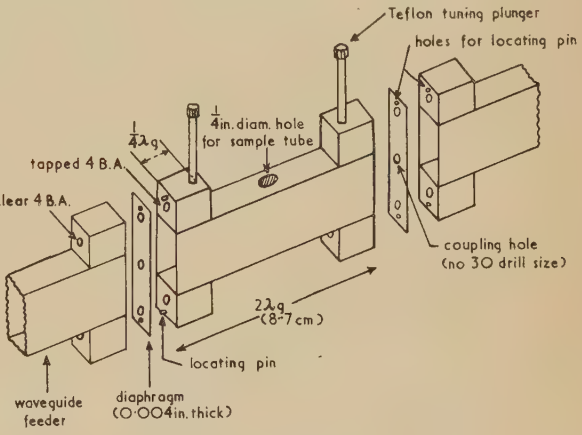
Contribution No. 567 Forest Biology Division, Research nch, Department of Agriculture, Ottawa, Canada.

Tunable wave-guide cell cavity for an electron spin resonance spectrometer†

By J. E. Bennett, B.Sc., Ph.D., A.Inst.P., and E. J. H. Morgan, "Shell" Research Ltd., Thornton Research Centre, Chester

[*Note first received* 30 *April, and in final form* 19 *June*, 1959]

A wave-guide cell cavity for use with a 3·2 cm wavelength spectrometer is shown in the figure. The salient features are:



Tunable wave-guide cell cavity

(i) simplicity of construction. The cavity is basically a length of standard 3·2 cm wave-guide, and can be dismantled easily for cleaning or changing the diaphragms;

(ii) the use of dielectric plungers to compensate for the variation in the tuning of the cavity produced by different samples;

(iii) the small overall width of the cavity (½ in.), which allows a narrow magnet gap to be used.

† Reproduced by permission of "Shell" Research Ltd.

Sensitive method for the measurement of small rotations

By R. J. King, Ph.D., and J. W. Gates, M.Sc., A.Inst.P., Light Division, National Physical Laboratory, Teddington, Middlesex

[*Note received* 8 *May*, 1959]

The automatic recording saccharimeter‡ developed at the National Physical Laboratory is in effect an instrument for measuring small rotations to an extremely high accuracy. It may therefore find important applications in fields quite unrelated to polarimetry; for example in the alinement of machine tool beds or slides.

---

‡ Gates, J. W. *Chem. and Industr.*, p. 190 (1958).

Briefly, the original instrument consists of the usual crossed polarizer and analyser, the plane of polarization of light emerging from the former being modulated by means of a Faraday cell carrying alternating current. Any rotation produced by an optically active specimen (corresponding to the polarizer and analyser not being in the exact crossed position) results in an out-of-balance signal from a photomultiplier. This is amplified and then rectified by a phase-sensitive detector. After further amplification, the rectified output is fed to a second, compensating, Faraday cell, so that the instrument automatically remains balanced. By employing negative feedback, the system is made largely independent of fluctuations in the power supply and the lamp brightness. The rotation due to the specimen (or the departure of the polarizer and analyser from the crossed position) is then proportional to the current in the compensating Faraday cell.

It is clear therefore that this system provides an extremely sensitive method for the orientation of one component relative to a second, in a plane perpendicular to the line joining the two components. In this application, the two components may be an appreciable distance apart, the polarizer being rigidly attached to one component and the analyser to the other. For this purpose, the compensating Faraday cell can be dispensed with and the system used at the null position (i.e. the correct orientation being obtained when there is zero output from the amplifier).

A number of different optical systems can be used quite conveniently, one arrangement being shown in Fig. 1. An enlarged image of the pinhole *H*, illuminated by a tungsten filament lamp is focused by lens *C* at the stop *S via* the plane mirror *M*. The polarizer *P* (a sheet of Polaroid) is situated directly in front of the mirror, and is slightly tilted to prevent the unpolarized reflexion from its front surface being incident on *S*. The Faraday cell *F* and analyser *A* are located in front of *S* as shown. By the use of suitable screening and baffles in the collecting system in front of the photomultiplier, the instrument can be made insensitive to normal room illumination. The light source need only be of low intensity, a 4 W bulb being adequate for operation with a separation of polarizer and analyser of over ten feet. Monochromatic illumination is not required.

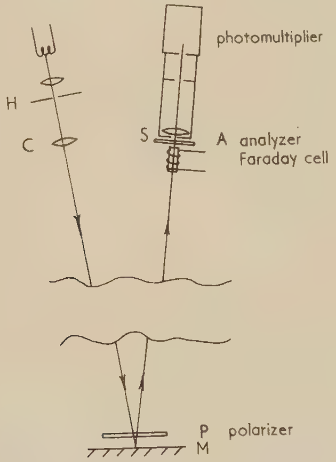


Fig. 1. Optical arrangement with rotatable polarizer

The location of both the light source and the phot
multiplier at one end of the system may be particula
convenient in certain applications, reducing to a minim
the number of components near to the unit to be orientat
A second arrangement possessing this feature, and with t
advantage that its optical axes are parallel, is shown in Fig.
In this system, the polarizer *P* and analyser *A* are fixed
the positions shown, and the unit to be orientated is attach

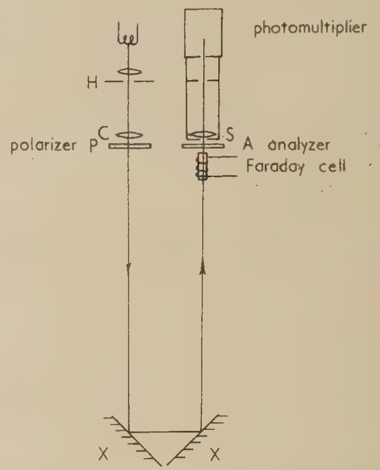


Fig. 2. Optical arrangement with rotatable mirrors

to the two front-surface metallized mirrors *XX*, set at rig
angles to each other, and preferably with the roof edg
formed parallel or perpendicular to the plane of the incide
vibration. A small rotation θ of the mirrors will then produ
a rotation 2θ of the plane of polarization of the emerge
light. Although after reflexion at the two mirrors the lig
may be slightly elliptically polarized, this does not sig
ficantly affect the functioning of the system, which thus h
the further advantage of possessing double the sensitivity
the arrangement of Fig. 1. Rotation of the mirrors w
produce a movement of the image of the pinhole, but th
will not be significant over the small angles under consider
tion. Finally it should be mentioned that a mirror syste
can be dispensed with and all the components arranged alo
the one axis. With the component under test attached to t
polarizer, this system can be made extremely insensitive
yaw of the test member (i.e. approximately 1000 times le
sensitive than to the rotation under measurement).

A system of the type shown in Fig. 1 was calibrated
measuring the amplifier output due to a small rotation of th
polarizer. This rotation was measured with an autocoll
mator by viewing a mirror attached to the polarizer mou
with its surface parallel to the axis of rotation. It was foun
that a given orientation could be repeated to better than o
second of arc, the fluctuations of the output meter corr
sponding to a r.m.s. angular value of approximately $1\frac{1}{2}$
This fluctuation level was obtained when both units (polariz
and analyser) were rigidly attached to the same support. O
mounting the two units on separate steel tables the fluctua
tions increased appreciably, presumably due to relati
movement of the two tables.

For the continuous recording of angular position over
period of time, the seond, compensating, Faraday cell ca
be introduced and the feedback current measured with
recorder. This provides an elegant method for recording, fo
example, the wind of a lathe bed, a measurement whic
cannot be conveniently made with an autocollimator. Th

e of linear response in this system depends on the maxi-
1 current output from the amplifier and the characteristics
ne compensating Faraday cell (i.e. the number of turns
ire, and the length and Verdet constant of the glass core).
1 a Faraday cell consisting of a 5 cm rod of Chance
EDF glass No. 030181, wound with 38 000 turns of
.w.g. enamelled copper wire, the maximum current
out of 8 mA corresponded to a rotation of approximately
.

he work described above has been carried out as part of
research programme of the National Physical Laboratory,
 this paper is published by permission of the Director of
Laboratory.

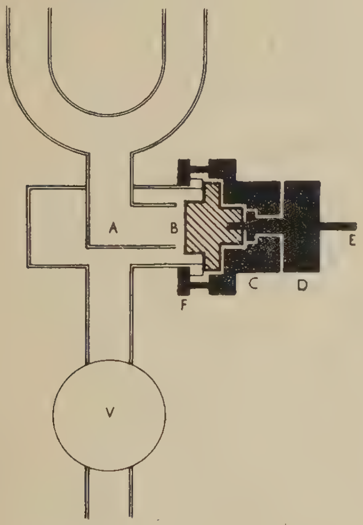
ple method for the control of the liquid level in a manometer

y John G. Cunningham, M.A.,* Laporte Titanium Research Department, Luton, Beds.

[*Note first received 27th May, and in final form 28 July,* 1959]

nany manometer systems it is necessary to bring the id in one limb to a fixed mark. A simple and accurate nod for performing this operation has been developed g the valve described below.†

ne experimental arrangement is shown in the diagram. glass body of the valve *A* is sealed at its open end by a prene rubber member *B*. The movement of the centre



lethod for the control of the liquid level in a manometer

? is controlled by the metal rod *E* which is sealed into the per and which may be moved in and out by the knob *D* which it is threaded. The knob *D* rotates in the metal nber *C* which, in turn, is held to the glass by the flange hus sealing the neoprene member around its periphery. vement of the rod *E* inwards distorts the rubber and reases the volume available to the manometric liquid. In extreme, the inner tube of *A* is sealed, isolating the two ves of the valve.

o use this valve as a fine control for the liquid level in a nometer, it is necessary to introduce a second valve *V*. The liquid is forced up the manometer until it nears the required level, and *V* is then closed. This isolates a fixed volume of liquid in the manometer. Fine control of the liquid level is now obtained by movement of the centre of the neoprene member. This method gives an accurate control of the level, and also allows small changes in pressure to be measured without reconnecting the manometer to the reservoir.

This system is at present employed in these laboratories using a similar diaphragm valve at *V*. This provides a completely grease-free system and prevents contamination of the manometric liquid.

The author wishes to thank the Directors of Laporte Titanium Limited for permission to publish this note.

Now at Gillette Research Laboratories, Isleworth, Middlesex.
Available from G. Springham and Co. Ltd., Harlow New
/n, Essex.

Device for graduating test-tubes and similar glassware

By J. W. Porteous, Ph.D., Department of Biological Chemistry, Marischal College, University of Aberdeen

[*Note first received* 13 *April, and in final form* 4 *June*, 1959]

Many analytical techniques call for test-tubes graduated to contain a given volume: for example, in the micro-estimation of phosphate,(1) or of pyruvate,(2) the whole estimation is carried out in a Pyrex test-tube graduated at 10 ml; in the micro-determination of reducing sugars,(3) the procedure requires a test-tube graduated at 12·5 or 25 ml.

The apparatus consists of three parts: the scaffolding, the female and male tube-"chucks" and the diamond pencil holder. These are described below.

The scaffolding (Fig. 1) is constructed from a base of cast iron, three steel rods and a triangular aluminium platform fixed to the top of the rods to render the scaffolding rigid. Between the top platform and the base is interposed a further platform fixed to three brass bushes which are a sliding fit on the rods; one of the bushes is fitted with a thumb-screw to lock the movable platform at any position between the base and the uppermost fixed platform. The two platforms are drilled centrally to take a rotatable rod.

The female tube-"chuck" (Fig. 1) is forced on to a ball race which is bolted through its centre into the base of the scaffolding and in line with the rotatable rod. The "chuck" is made from a cylindrical block of brass, the upper face of which is turned out to give a hollow inverted cone. The diameter of the base of the cone is slightly larger than the diameter of the largest tube to be calibrated, and a thin sheet of rubber is bonded to the inner surface of the cone.

The upper, male, "chuck" (Fig. 1) is similarly made to give a solid cone covered with rubber. The rotatable rod is threaded and locked into the upper face of the male "chuck"; a compression spring, sandwiched between two washers, is placed on the rod before inserting the assembly upwards through the movable and fixed platforms. A knurled wheel is fixed by a grub screw to the rod above the fixed platform and limits the fall of the chuck when a test-tube is removed.

The diamond pencil holder (Figs. 1 and 2), consist of an aluminium swinging arm *A* fixed through a spacing piece *P* to bush *B*, which is a sliding fit on one of the uprights of the scaffolding. Bush *B* is sandwiched between collars C_1 and C_2 spanned by and fixed to a bridge *D*. Collar C_1 carries a thumb-screw *T*, which thus holds bush *B* at any vertical position between the base and the movable platform, while allowing arm *A* to swing in a horizontal plane between collars C_1 and C_2.

A laboratory diamond pencil is retained by a grub-screw in an aluminium bush *I* threaded into arm *A*. A hole in the centre of the vertical face of guide piece *J* is alined with the axial hole in *I* and permits the diamond pencil to project past the free face of *J*; *A* and *J* are bolted together. Holes K_1 and K_2 are drilled and tapped in the top and bottom horizontal faces of *J*.

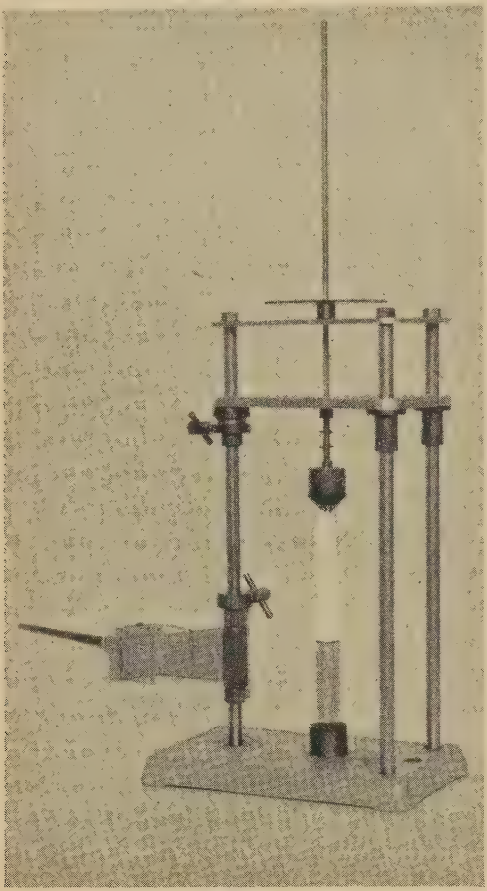


Fig. 1. The completed apparatus with a test-tube, held between the self-centring chucks, ready for marking with the diamond held in the swinging arm.

Overall dimensions: base, 7·5 by 4·5 in; height of scaffolding, 12 in.

The diamond holder is completed by a sighting device consisting of an aluminium plate *L*, equal in width to *J*, and with a central slot *M* cut through it. Flush with the top and bottom horizontal faces of *L* are fitted square-section blocks N_1 and N_2, through each of which is drilled a hole in line with and to clear the thread sizes of holes K_1 and K_2. To the vertical sides of *L*, N_1 and N_2 are fixed Perspex sheets O_1 and O_2. A fine line is scribed across the outer face of each Perspex sheet, the back edges of which are in line with the back faces of N_1 and N_2 and bear against the face of arm *A*. Counter adjustment of screws Q_1 and Q_2 moves the sighting device upwards or downwards, the guide *J* preventing lateral movement.

To adjust the sighting device, a test tube is placed betw the chucks and a line scribed round the tube as descri below. If the sight lines on the Perspex sheets are no line with the scribed line on the tube, the sighting devic adjusted until coincidence is obtained. Subsequent adjustment is unnecessary unless the diamond penci disturbed.

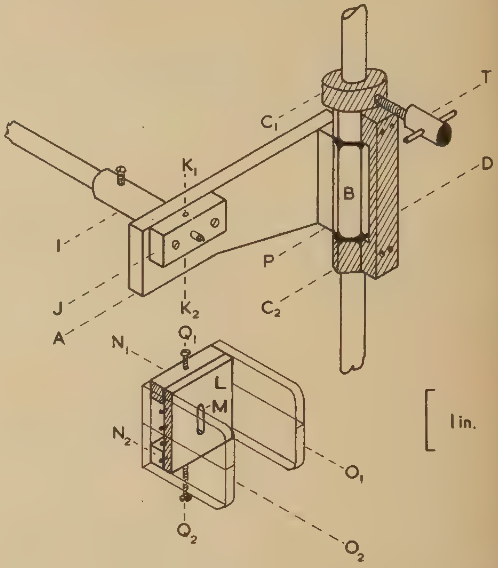


Fig. 2. Isometric projection of the diamond perc holder and, temporarily removed from it, the adjusta sighting device designed to eliminate errors of parall

Water of the required volume is delivered into each t to be calibrated. The movable platform (Fig. 1) is adju so that on compressing the male chuck upwards the bot of the tube will seat into the female chuck and the top o tube will pass under the male chuck; the latter is then rele and seats into the open end of the tube which is thus autom cally gripped and centred irrespective of its diameter. I vided tubes of approximately uniform length are dealt as a batch, the movable platform is not disturbed du calibration of the tubes. The diamond holder is adju vertically on the scaffolding until the sight lines coin with the meniscus of the liquid in the tube, the holde locked in this position and the diamond swung on its arm press lightly against the glass tube; the tube is rotated o to complete the calibration for one volume in one tube.

Approximately one hundred tubes can be calibrated 25 ml in five hours, including the initial filling of the tu from an automatic burrette.

The apparatus described was constructed to the auth design by Mr. A. G. Silver in the departmental worksh Fig. 1 is reproduced from a photograph by Mr. J. Jameis

REFERENCES

(1) Long, C., *Biochem. J.*, **37**, p. 215 (1943).
(2) Long, C., *Biochem. J.*, **36**, p. 807 (1942).
(3) Nelson, N., *J. Biol. Chem.*, **153**, p. 375 (1944).

Correspondence

Cryostat for reactor irradiation in liquid nitrogen

irradiation in the graphite reactor BR I at Mol, we have t a vertical liquid nitrogen cryostat, which is very similar ıe one constructed at Harwell and described by Thompson Jefferson-Loveday on pp. 397–399 of the November 1958 e of this *Journal*. We did not, however, use a convertor. ight be worth while to indicate some of the improvements le, as well as to give some results of our experience during first months of operation.

he thermal flux in BR I at the spot of the cold samples is ut $1\cdot5 \times 10^{12}$ neutron cm^{-2} s^{-1} and the epithermal flux bout equal in magnitude.

/e do not use a pump to inject the liquid nitrogen into the ostat, but only apply the under-pressure of about 130 mm ıercury from the normal reactor ventilation. This under-sure is reduced by a needle valve in order to obtain tinuous injection at a small rate. When the cold junction perature of the iron-constantan thermocouple in the ostat rises about 2° C, the needle valve is bypassed for , causing a considerable increase of the injection rate. s happens at regular intervals of about 12 min. The ount of liquid nitrogen injected each time is so small that reactivity change is barely detectable, so that other experi-ts are not disturbed. A pump is only used to cool the m cryostat or to continue injection after shut-down of the tor.

)utgassing of Sil-o-cel powder (by Johns-Manville Co. .) is difficult. We prefer grains of perlite ($SiO_2 \simeq 76\%$; $O_3 \simeq 16\%$; Fe_2O_3, 1–2%) as filling for the vacuum jacket ounding the injection tube. In this way a vacuum of 10^{-2} mm of mercury can be reached in less than one hour, and also leak detection is easier. Perlite was also found to have quite good shielding properties.

On the top of the reactor, in the immediate vicinity of the head of the cryostat and the injection tube, the following doses have been measured: $\gamma < 7$ mr/h, thermal neutrons less than 3 mrem/h, fast neutrons not detectable.

No trace of corrosion has appeared on the aluminium at the inside of the cryostat after six successive irradiation periods of eleven days, although no special attention has been paid to flushing the cryostat with dry nitrogen gas during the warming up after each irradiation period. The liquid nitrogen used contained less than $0\cdot5\%$ oxygen and less than $0\cdot5\%$ argon.

The cryostat has been in operation now for five months. The consumption of liquid nitrogen is lower than $17\cdot5$ l. per twenty-four hours, all losses included (e.g. those in the liquid nitrogen reservoir). This seems to prove that it is not necessary to use very pure nitrogen under pressure in a closed circuit, with a consumption of 380 l. per twenty-four hours, in order to avoid an explosion.*

The complete description of the apparatus appears in a separate report.†

I am indebted to Mr. M. W. Thompson for helpful advice and to Dr. J. Spaepen for continuous interest.

Studiecentrum voor Kernenergie, G. Bortels
Mol, Belgium. [27 *April*, 1959]

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* Sartain, C. C., and Yockey, H. P. Cryostat for reactor irradiation. *Rev. Sci. Instrum.*, **29**, p. 118 (1958).

† Bortels, G. *Vertical cryostat for irradiations in liquid nitrogen.* Internal Report, R 1640 (Studiecentrum voor Kernenergie).

NOTES AND NEWS

New books

clear electronics. (Wien: International Atomic Energy Agency, 1959.) Pp. 451. Price 24*s*.

e papers, and the discussions upon them, read during the olloque international sur l'electronique nucleaire" organ-d by the Société Française des radio-electriciens in Paris September 1958 are given in this volume. The colloquium tained five sessions under the following titles:—Scintilla-n radiation detectors; Radiation detectors using ionizing thods, and gamma-ray spectrometers; Pulse technique: t electronics; Pulse technique: classical electronics; actor control: measurements. Some of the papers are blished in French but the majority are in English.

niconductor abstracts. Vol. 4. Edited by E. Paskell. (New York: John Wiley and Sons Inc.; London: Chapman and Hall Ltd., 1959.) Pp. 456. Price 96*s*.

e present volume is a continuation of a series which was nned to appear annually. Previous volumes have covered niconductor research for the years 1952–1955; this volume es abstracts of papers which were published in 1956. It great pity that it should have taken so long in preparation its value would have been greatly enhanced had it appeared oner.

There is no sign of any fall-off in the large number of papers published annually on semiconductors; the number of abstracts in the present volume is 1462 as compared with 1258 in the previous issue. The size and value of the abstracts vary a good deal but these are mostly quite informative, and a good appreciation has been shown of the relative importance of the different papers as indicated by the extent of the abstracts; a great deal of painstaking work has clearly gone into their preparation.

The subject-matter is divided according to materials; silicon and germanium are represented by 381 abstracts, other materials being classified in groups; a special section is devoted to theoretical papers. The volume will now be mainly useful for reference purposes and not for obtaining up-to-date information quickly, since with a subject advancing so rapidly, abstracts of papers three years old can hardly give an adequate picture of the present situation. Accordingly the book will mainly be in demand by libraries. These will want to complete the series, since most laboratories dealing with semiconductor research will have the previous issues; in any case the price will put the book out of the range of most individuals. Like the previous volume of the series it is attractively bound and well produced. It is hoped that the next two volumes of the series giving the abstracts for 1957 and 1958 will not be long delayed.

R. A. Smith

Frottement et échanges thermiques dans les gaz raréfiés. By F. MARCEL DEVIENNE. (Paris: Gauthier-Villars, 1958.) Pp. viii + 135. Price 2000 fr.

This paper-bound monograph is the third by Dr. Devienne dealing with the properties of rarefied gases. A foreword by Prof. M. Edmund Brun styles it a précis. The nine chapter headings include the following aspects of the subject: flow of rarefied and ultra-rarefied gases, relation between coefficient of friction and the exchange factor of the quantity of flow, flow of gas in the intermediate regime, interchanges and thermal exchanges between a rarefied gas and a moving body (super-aerodynamics and super-aerodynamic heating). Applications dealt with include diffusion and molecular pumps, separation of isotopes, heating of bodies in the upper atmosphere and upper atmosphere density determinations from trajectories of meteors.

A bibliography of nearly a hundred papers, the majori of the past decade, forms a feature which should commen the book to those interested in the subject.

R. W. POWELL

The transistor era. Edited by C. C. GEE and C. A. MARSHAI (London: Heywood and Co. Ltd., 1959.) Pp. 9 Price 5*s*.

The main aim of this book is to provide a source of referen to the availability of transistors and allied equipment man factured in the United Kingdom; but in order to place t British contribution in a world setting a survey is also includ of semi-conductor manufacturers in other countries.

The products covered are transistors, diodes and rectifie and photosensitive devices.

Notes and comments

BINDING ORDERS

Orders and enquiries about the binding of back-numbers of this *Journal* should be sent direct to Messrs. E. A. Weeks and Son, 168 Gower Street, London, N.W.1. (EUSton 4674), and *not* to the Institute. The price for binding has been reduced and will in future be 22*s*. post free (standard case). Separate cases are also available at a reduced rate of 13*s*. 6*d*. The indexes and title-pages will be issued with the March 1960 issue of this *Journal*.

The Physical Society's annual exhibition of scientific instruments and apparatus

The Physical Society announces that its forty-fourth annual exhibition will be held at the Royal Horticultural Society's Old and New Halls, Westminster, London, S.W.1, from 18–22 January, 1960 (inclusive).

Entrance to the exhibition is by ticket only and these may be obtained, free of charge, from the offices of the Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.1. Members of The Institute of Physics may obtain tickets from the Institute. The handbook of scientific instruments and apparatus published in connexion with the exhibition is available from the Society, price 6*s*., by post 8*s*.

Creep Information Centre

A Creep Information Centre is being established at the National Engineering Laboratory of the Department of Scientific and Industrial Research, East Kilbride, Glasgow. This centre is intended to fill the need for an information centre for data on all strength properties of high-temperature steels, and it is intended that it shall eventually become the national centre for information on the strength of high-temperature materials.

It is hoped to collect all the available data on creep and rupture properties of convential high-temperature materials; as far as commercial security allows, data on the strength of British high-temperature materials will be iss in a form agreed by the committees of the British Standa Institution. It may be possible to extend the scheme at later date to cover all other mechanical properties, as w as information about test procedures and testing machin

The centre is now ready to accept relative data particul on creep properties, for which the industrial demand greatest.

British Journal of Applied Physics

Contents of the December issue

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